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ANNUAL REPORT OF THE
BOARD OF REGENTS OF
THE SMITHSONIAN
INSTITUTION

SHOWING THE
OPERATIONS, EXPENDITURES, AND
CONDITION OF THE INSTITUTION
FOR THE YEAR ENDED JUNE 30

1944



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LETTER OF TRANSMITTAL

SMITHSONIAN INSTITUTION,
Washington, November 20, 1944.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and conditions of the Smithsonian Institution for the year ended June 30, 1944. I have the honor to be,

Respectfully,

A. WETMORE, *Acting Secretary.*

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THE SMITHSONIAN INSTITUTION

June 30, 1944

Presiding Officer ex officio.—FRANKLIN D. ROOSEVELT, President of the United States.

Chancellor.—HARLAN F. STONE, Chief Justice of the United States.

Members of the Institution:

FRANKLIN D. ROOSEVELT, President of the United States.

HENRY A. WALLACE, Vice President of the United States.

HARLAN F. STONE, Chief Justice of the United States.

CORDELL HULL, Secretary of State.

HENRY MORGENTHAU, Jr., Secretary of the Treasury.

HENRY L. STIMSON, Secretary of War.

FRANCIS BIDDLE, Attorney General.

FRANK C. WALKER, Postmaster General.

JAMES V. FORRESTAL, Secretary of the Navy.

HAROLD L. ICKES, Secretary of the Interior.

CLAUDE R. WICKARD, Secretary of Agriculture.

JESSE H. JONES, Secretary of Commerce.

FRANCES PERKINS, Secretary of Labor.

Regents of the Institution:

HARLAN F. STONE, Chief Justice of the United States, Chancellor.

HENRY A. WALLACE, Vice President of the United States.

ALDEN W. BARKLEY, Member of the Senate.

BENNETT CHAMP CLARK, Member of the Senate.

CLARENCE CANNON, Member of the House of Representatives.

FOSTER STEARNS, Member of the House of Representatives.

EDWARD E. COX, Member of the House of Representatives.

FREDERIC A. DELANO, citizen of Washington, D. C.

ROLAND S. MORRIS, citizen of Pennsylvania.

HARVEY N. DAVIS, citizen of New Jersey.

ARTHUR H. COMPTON, citizen of Illinois.

VANNEVAR BUSH, citizen of Washington, D. C.

FREDERICK C. WALCOTT, citizen of Connecticut.

Executive Committee.—FREDERICK A. DELANO, VANNIEVAR BUSH, CLARENCE CANNON, Secretary.—CHARLES G. ABBOT.

Assistant Secretary.—ALEXANDER WETMORE.

Administrative assistant to the Secretary.—HARRY W. DORSEY.

Treasurer.—NICHOLAS W. DORSEY.

Chief, editorial division.—WEBSTER P. TRUE.

Librarian.—LEILA F. CLARK.

Personnel officer.—B. T. CARWITHEN.

Property clerk.—JAMES H. HILL.

UNITED STATES NATIONAL MUSEUM

Keeper ex officio.—CHARLES G. ABBOT.

Director.—ALEXANDER WETMORE.

Associate Director.—JOHN E. GRAY.

SCIENTIFIC STAFF

DEPARTMENT OF ANTHROPOLOGY:

Frank M. Seizler, head curator; A. J. Andrews, chief preparator.

Division of Archeology: Neil M. Judd, curator; Waldo R. Wedel, associate curator; R. G. Palne, scientific aid; J. Townsend Russell, honorary assistant curator of Old World archeology.

Division of Ethnology: H. W. Krieger, curator; Arthur P. Rice, collaborator.

Division of Physical Anthropology: T. Dale Stewart, curator; M. T. Newman, associate curator.*

Collaborator in anthropology: George Grant MacCurdy.

DEPARTMENT OF BIOLOGY:

Waldo L. Schmitt, head curator; W. L. Brown, chief taxidermist;

Alme M. Awl, illustrator.

Division of Mammals: Remington Kellogg, curator; D. H. Johnson, associate curator*; H. Harold Shamel, scientific aid; A. Brazier Howell, collaborator; Gerrit S. Miller, Jr., associate.

Division of Birds: Herbert Friedmann, curator; H. G. Delgman, associate curator; Alexander Wetmore, custodian of alcoholic and skeleton collections; Arthur C. Bent, collaborator.

Division of Reptiles and Batrachians: Doris M. Cochran, associate curator.

Division of Fishes: Leonard P. Schultz, curator; E. D. Reid, scientific aid.

Division of Insects: L. O. Howard, honorary curator; Edward A. Chapin, curator; R. E. Blackwelder, associate curator.*

Section of Hymenoptera: S. A. Rohwer, custodian; W. M. Mann, assistant custodian; Robert A. Cushman, assistant custodian.

Section of Myriapoda: O. F. Cook, custodian.

Section of Diptera: Charles T. Greene, assistant custodian.

Section of Coleoptera: L. L. Buchanan, specialist for Casey collection.

Section of Lepidoptera: J. T. Barnes, collaborator.

Section of Forest Tree Beetles: A. D. Hopkins, custodian.

Division of Marine Invertebrates: Waldo L. Schmitt, curator; James O. Maloney, aid; Mrs. Harriet Richardson Searle, collaborator; Max M. Ellis, collaborator; J. Percy Moore, collaborator; Joseph A. Cushman, collaborator in Foraminifera.

Division of Mollusks: Paul Bartsch, curator; Harald A. Rehder, associate curator; Joseph P. E. Morrison, assistant curator.

Section of Helminthological Collections: Benjamin Schwartz, collaborator.

Division of Echinoderms: Austin H. Clark, curator.

Division of Plants (National Herbarium): W. R. Maxon, curator; Ellsworth P. Killip, associate curator; Emery C. Leonard, assistant curator; Conrad V. Morton, assistant curator; Egbert H. Walker, assistant curator; John A. Stevenson, custodian of C. G. Lloyd mycological collection.

Section of Grasses: Agnes Chase, custodian.

Section of Cryptogamic Collections: O. F. Cook, assistant curator.

Section of Higher Algae: W. T. Swingle, custodian.

Section of Lower Fungi: D. G. Fairchild, custodian.

Section of Diatoms: Paul S. Conger, associate curator.

Associates in Zoology: Theodore S. Palmer, William B. Marshall, A. G. Boving, W. K. Fisher, C. R. Shoemaker, E. A. Goldman.

Associates in Botany: Henri Pittier, F. A. McClure.

*Now on war duty.

DEPARTMENT OF BIOLOGY—Continued.

Collaborator in Zoology: Robert Sterling Clark.

Collaborators in Biology: A. K. Fisher, David C. Graham.

DEPARTMENT OF GEOLOGY:

R. S. Bassler, head curator; Jessie G. Beach, aid.

Division of Mineralogy and Petrology: W. F. Foshag, curator; E. P. Henderson, associate curator; B. O. Reberholt, scientific aid; Frank L. Hess, custodian of rare metals and rare earths.

Division of Invertebrate Paleontology and Paleobotany: Gustav A. Cooper, curator.

Section of Invertebrate Paleontology: T. W. Stanton, custodian of Mesozoic collection; J. B. Reeside, Jr., honorary custodian of Mesozoic collection; Paul Bartsch, curator of Cenozoic collection.

Division of Vertebrate Paleontology: Charles W. Gilmore, curator; C. Lewis Gazin, associate curator*; Norman H. Boss, chief preparator.

Associates in Mineralogy: W. T. Schaller, S. H. Perry.

Associate in Paleontology: T. W. Vaughan.

Associate in Petrology: Whitman Cross.

DEPARTMENT OF ENGINEERING AND INDUSTRIES:

Carl W. Mitman, head curator.

Division of Engineering: Carl W. Mitman, head curator in charge; Frank A. Taylor, curator.*

Section of Transportation and Civil Engineering: Frank A. Taylor, in charge.*

Section of Aeronautics: Paul E. Garber, associate curator,* F. C. Reed, acting associate curator.

Section of Mechanical Engineering: Frank A. Taylor, in charge.*

Section of Electrical Engineering and Communications: Frank A. Taylor, in charge.*

Section of Mining and Metallurgical Engineering: Carl W. Mitman, in charge.

Section of Physical Sciences and Measurement: Frank A. Taylor, in charge.*

Section of Tools: Frank A. Taylor, in charge.*

Division of Crafts and Industries: Frederick L. Lewton, curator; Elizabeth W. Rosson, assistant curator.

Section of Textiles: Frederick L. Lewton, in charge.

Section of Woods and Wood Technology: William N. Watkins, associate curator.

Section of Chemical Industries: Frederick L. Lewton, in charge.

Section of Agricultural Industries: Frederick L. Lewton, in charge.

Division of Medicine and Public Health: Charles Whitebread, associate curator.

Division of Graphic Arts: R. P. Tolman, curator.

Section of Photography: A. J. Olmsted, associate curator.

DIVISION OF HISTORY: T. T. Belote, curator; Charles Carey, associate curator; J. Russell Sirlouis, scientific aid; Catherine L. Manning, assistant curator (philately).

ADMINISTRATIVE STAFF

Chief of correspondence and documents.—H. S. BRYANT.

Assistant chief of correspondence and documents.—L. E. COMMERFORD.

*Now on war duty.

Superintendent of buildings and labor.—L. L. OLIVER.

Assistant superintendent of buildings and labor.—CHARLES C. SINCLAIR.

Editor.—PAUL H. OENSEL.

Accountant and auditor.—N. W. DORSEY.

Photographer.—G. I. HIGHTOWER.

Property officer.—A. W. WILBING.

Assistant librarian.—ELISABETH H. GAZIN.

NATIONAL GALLERY OF ART

Trustees:

THE CHIEF JUSTICE OF THE UNITED STATES, *Chairman*.

THE SECRETARY OF STATE.

THE SECRETARY OF THE TREASURY.

THE SECRETARY OF THE SMITHSONIAN INSTITUTION.

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FERDINAND LAMMOT BELIN.

DUNCAN PHILLIPS.

SAMUEL H. KRESS.

CHESTER DALE.

President.—DAVID K. E. BRUCE.

Vice President.—FERDINAND LAMMOT BELIN.

Secretary-Treasurer.—HUNTINGTON CAIRNS.

Director.—DAVID E. FINLEY.

Administrator.—H. A. MCBRIDE.

General Counsel.—HUNTINGTON CAIRNS.

Chief Curator.—JOHN WALKER.

Assistant Director.—MACGILL JAMES.

NATIONAL COLLECTION OF FINE ARTS

Acting Director.—RUEL P. TOLMAN.

FREER GALLERY OF ART

Director.—A. G. WENLEY.

Assistant Director.—GRACE DUNHAM GUEST.

Associate in research.—J. A. POPE.

BUREAU OF AMERICAN ETHNOLOGY

Chief.—MATTHEW W. STIRLING.

Senior ethnologists.—H. B. COLLINS, JR., JOHN P. HARRINGTON, JOHN R. SWANTON.

Senior archeologist.—FRANK H. H. ROBERTS, JR.

Senior anthropologist.—H. G. BARNETT.

Senior ethnologist.—W. N. FENTON.

Editor.—M. HELEN PALMER.

Librarian.—MIRIAM B. KETCHUM.

Illustrator.—EDWIN G. CASSEDY.

INSTITUTE OF SOCIAL ANTHROPOLOGY.—JULIAN H. STEWARD, *Director*; ALFRED MÉTRAUX, *Assistant Director*.

INTERNATIONAL EXCHANGE SERVICE

Secretary (in charge).—CHARLES G. ABBOT.

Acting Chief Clerk.—F. E. GASS.

NATIONAL ZOOLOGICAL PARK

Director.—WILLIAM M. MANN.

Assistant Director.—ERNEST P. WALKER.

ASTROPHYSICAL OBSERVATORY

Director.—CHARLES G. ABBOT.

DIVISION OF ASTROPHYSICAL RESEARCH: Loyd B. Aldrich, assistant director;
William H. Hoover, senior astrophysicist.

DIVISION OF RADIATION AND ORGANISMS: Earl S. Johnston, assistant director;
Edward D. McAllister, senior physicist; Leland B. Clark, engineer (precision
instruments); Robert L. Weintraub, associate biochemist; Leonard Price, junior
physicist (biophysics).

REPORT OF THE SECRETARY OF THE SMITHSONIAN INSTITUTION

C. G. ABBOT

FOR THE YEAR ENDED JUNE 30, 1944

To the Board of Regents of the Smithsonian Institution.

GENTLEMEN: I have the honor to submit herewith my report showing the activities and condition of the Smithsonian Institution and the Government bureaus under its administrative charge during the fiscal year ended June 30, 1944. The first 12 pages contain a summary account of the affairs of the Institution; it will again be noted that many activities usually included in this section are missing, wartime conditions having forced their suspension. Appendixes 1 to 10 give more detailed reports of the operations of the National Museum, the National Gallery of Art, the National Collection of Fine Arts, the Freer Gallery of Art, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, which now includes the divisions of astrophysical research and of radiation and organisms, the Smithsonian library, and of the publications issued under the direction of the Institution. On page 110 is the financial report of the executive committee of the Board of Regents.

Change in the Secretaryship.—This will be my last report, as on June 20, 1944, I addressed the following communication to the Board of Regents:

Having occupied the post of Secretary of the Smithsonian Institution since February 1928, and of Acting Secretary for one year prior to that, and having passed the age of 72 years, I wish to resign from that office, my resignation to take effect as of July 1, 1944.

I feel that it would be quite unfair to the Institution to continue in this responsible position when in the nature of things my capacity must gradually begin to decline. In tendering my resignation, I wish to express my gratitude to the Board for its kindly and helpful attitude, and my desire to be of any service which the Board or my successor may feel disposed to suggest.

Accordingly on July 1, 1944, I ceased to be Secretary of the Institution, and Dr. Alexander Wetmore, Assistant Secretary, took over the duties of the position as Acting Secretary. I wish to record here publicly my appreciation of the unfailing helpfulness and support

accorded to me by the staff of the Institution, and to bespeak for my successor and for the Institution their continued loyalty and devoted service.

WARTIME ACTIVITIES OF THE INSTITUTION

During another full year of war, the Institution again utilized its capabilities to the fullest extent in aiding the Army and Navy and the various war agencies. Its normal peacetime research and exploration program was largely abandoned except for those projects designed to promote better cultural relations with the other American republics, and its publications were restricted almost entirely to papers having a bearing on the war or on the other Americas. To visitors to the Institution, these changes would not be apparent, as its visible features—museums and art galleries—have continued to operate on full schedule. In fact, hours of opening have been expanded to include Sundays for the benefit of the large numbers of service personnel stationed around Washington and passing through. But the time of the staff—aside from necessary curatorial work and the recording of observations the cessation of which would result in gaps in the scientific record—has been devoted largely to furnishing technical information and assistance urgently needed by Army, Navy, and war agencies.

Strategic information to Army and Navy.—The scientific staff of the Institution and its branches includes specialists in many branches of biology, geology, anthropology, astrophysics, engineering, and technology, and these scientists have been called upon constantly since Pearl Harbor to answer questions confronting Army and Navy officials. The present war, covering as it does widely scattered regions of the earth, many of them little known to Americans, has required the assembling of large amounts of data on the peoples, geography, disease-harboring insects, animals and plants, and other features of these far-flung regions. The Smithsonian Institution has been able to furnish, both directly and through the Ethnogeographic Board, described below, replies to hundreds of urgent questions of this nature, and some staff members have been in almost constant consultation with Army and Navy officials. Furthermore, a number of war-connected research projects have been assigned to the Institution, and its laboratory facilities have been utilized from time to time for Army and Navy investigations.

Ethnogeographic Board.—As stated in my last report, the Ethnogeographic Board is a nongovernmental agency, set up jointly by the Smithsonian Institution, the National Research Council, the American Council of Learned Societies, and the Social Science Research Council, to serve as a clearinghouse between the Army, Navy,

and war agencies on the one hand, and the scientific and educational institutions of the Nation on the other. Many urgent reports and items of strategic information have been furnished by the Board principally on the peoples, geography, and related features of war areas. The offices of the Board are in the Smithsonian building, and three members of the Institution's staff were assigned to assist the Director, Dr. William Duncan Strong. The Army and Navy found the services of the Board so useful that each appointed liaison officers to facilitate contact. The Board plans to continue in operation as long as needed during the coming fiscal year.

Inter-American Cooperation.—Through invitation by other agencies and through its own initiative, the Institution engaged in a number of activities designed to promote better cultural relations with the other American republics. Work on the monumental Handbook of South American Indians, under the editorship of Dr. Julian H. Steward, was advanced materially. Volume 1, "The Marginal Tribes," and volume 2, "The Andean Civilizations," went to the printer toward the close of the fiscal year, and the manuscripts of volumes 3 and 4 were well on toward completion. The editorial work on this project is financed by the State Department, and the printing costs will be borne by the Bureau of American Ethnology, Smithsonian Institution, as the Handbook will appear in the Bureau's Bulletin series.

In September 1943 Dr. Steward was appointed Director of the Institute of Social Anthropology, an autonomous unit of the Bureau of American Ethnology reporting to the Secretary, created to carry out cooperative training in anthropological teaching and research with the other American republics as part of the program of the Interdepartmental Committee for Cooperation with the American Republics. The work of the Institute in Mexico was begun in co-operation with the Escuela Nacional de Antropología of the Instituto Nacional de Antropología e Historia, and plans were pending for work in several other American republics. Dr. Steward also served on the Temporary Organizing Committee of the Inter-American Society of Anthropology and Geography, which had been started on his initiative during the previous year. Dr. Ralph L. Beals served as secretary of the committee and editor of the quarterly journal of the Society, *Acta Americana*. Paid membership in the Society from all parts of the Americas reached a total of 800.

A valuable biological project is the publication by the Institution of a "Checklist of the Coleopterous Insects of Mexico, Central America, the West Indies, and South America," by Dr. R. E. Blackwelder. No list of this important insect group now exists, and entomologists of all the Americas will find it indispensable in future researches. The

first and second parts appeared in print during the year, and the third part was in press.

A number of scientists on the Institution's staff made trips to other American republics during the year in the furtherance of cooperative scientific projects in biology, geology, and anthropology.

Other wartime activities.—As stated above, for the benefit of military and naval personnel and war workers the Smithsonian and National Museum buildings have again been kept open all day on Sundays. To accomplish this with available funds, it was necessary to have the buildings closed on Monday mornings. Sunday Museum tours for service personnel were arranged in the Natural History building through cooperation with the U. S. O. A Field Collector's Manual in Natural History was published and distributed free on request to Army and Navy personnel. One thousand copies each were turned over to the Army and Navy for distribution through their own channels.

War Committee.—The Smithsonian War Committee appointed early in 1941, after canvassing fully all the possibilities of increasing the Institution's usefulness in the war and embodying the results of this study in recommendation for action, felt that its function was fulfilled and asked that it be dissolved. In assenting to the dissolution of the committee, I wrote to the chairman, C. W. Mitman, as follows:

I beg to express, for myself and on behalf of the Institution, a deep sense of the value of the work of the committee in these several years, and the feeling that those of its recommendations which have been carried through cannot but have been very helpful to the war effort.

SUMMARY OF THE YEAR'S ACTIVITIES OF THE BRANCHES OF THE INSTITUTION

National Museum.—Again this year the time of the scientific staff has been largely occupied with conferences on war problems with Army, Navy, and war agency officials and with furnishing technical information on requests to military and naval organizations. The Museum buildings have again been kept open all day on Sundays for the benefit of service personnel, and Sunday Museum tours were arranged for them in cooperation with the U. S. O. New accessions for the year totaled 239,640 specimens, an increase of more than 9,000 over last year. Among the outstanding additions to the collections were the following: In anthropology, an important lot of material from Indian sites on DeSoto's route through the southeastern United States in 1539-42, a collection pertaining to the Huichol Indians of northern Jalisco, Mexico, and an assemblage of Moro and Indonesian brasses and Philippine metalwork presented to the Tafts during their residence in the Philippines; in biology, 2,000 mammal specimens from Colombia collected by Philip Herschkovitz, a bird

collection from the same country numbering 3,281 specimens, more than 10,000 mosquito specimens from the sanitary and medical corps of the armed forces, a molluscan collection of 51,000 Jamaican Neritidae, the valuable Chickering herbarium of 10,550 plant specimens, and the Albert Mann diatom collection, which with the other material on hand in this field makes the Museum diatom collection one of the most important in the world; in geology, a number of important gems and minerals obtained through the Roebling, Chamberlain, and Canfield funds, 7 new meteorites, 6 of them undescribed falls, and 500 specimens of rare Paleozoic fossils collected by the curator during field work in Mexico; in engineering, a jeep, the prototype of these vehicles made famous by World War II, and a Winton automobile of 1903, the first automobile to be driven across the United States; in history, a number of Army and Navy medals and decorations of types established during the present war. The few expeditions that were in the field during the year were related directly or indirectly to the war. Visitors for the year numbered 1,532,765, an increase of 177,496 over last year; approximately 40 percent were service personnel. The Museum published an Annual Report, 3 Bulletins, 1 Contribution from the National Herbarium, and 14 Proceedings papers. Staff changes included the loss by death of the curator of invertebrate paleontology, Dr. Charles E. Resser; Dr. G. Arthur Cooper was appointed curator to succeed him.

National Gallery of Art.—Visitors to the Gallery totaled 2,060,071 for the year, the largest attendance since its opening. Thirty percent of the visitors were men and women in the armed services. Features of particular interest to service personnel were the Servicemen's Room, which provides a place of relaxation for them, the Sunday evening concerts, and the special exhibitions. The Board of Trustees was directed by the Treasury Department to assume custodianship of all works of art and exhibition material sent to this country for various exhibitions by the former French Government, and several officers of the Gallery were appointed to serve as officers of the American Commission for the Protection and Salvage of Artistic and Historic Monuments in War Areas, the headquarters of which are located in the Gallery building. In March 1944, at the request of the State Department, the Gallery established the Inter-American Office to act as the official Government clearinghouse for the exchange of information concerning art activities in the American republics. The Gallery accepted a number of gifts of paintings, prints, and drawings, including 8 paintings and 196 prints and drawings from Lessing J. Rosenwald. Among the 13 special exhibitions held during the year were a number relating to war subjects. More than 72,000 people attended the various programs conducted by the Gallery's educational

department; these included Gallery tours, discussions of the "Picture of the Week," and lectures on special topics.

National Collection of Fine Arts.—The annual meeting of the Smithsonian Art Commission was again omitted because of war conditions. The Commission lost one member by death—Dr. Frederick P. Keppel, a member since 1932. Four miniatures were acquired through the Catherine Walden Myer fund. Several proffered gifts of art works are being held for action of the Art Commission at its next meeting. A number of paintings and other art works have been accepted by the National Collection as loans; other paintings and miniatures belonging to the Collection have been lent to museums and art galleries, mostly for special exhibitions. Only one painting was purchased from the Henry Ward Ranger fund, "Fifteenth Century French Madonna and Child," by Harry W. Watrous. Eight special exhibitions were held during the year, as follows: Oil paintings and other art works by Ceferino Palencia, of Mexico; water colors of Mexico by Walter B. Swan, of Omaha, Nebr.; miniatures by 52 artists of the Pennsylvania Society of Miniature Painters; water colors and block prints by Ralph H. Avery, United States Navy; paintings by John Mix Stanley, Jane C. Stanley, and Alice Stanley Acheson; paintings and other art works by the National League of American Pen Women; "Portraits of Leading American Negro Citizens," by Mrs. Laura Wheeler Waring, of Philadelphia, and Mrs. Betsy Graves Reyneau, of Washington; and mural paintings from the caves of India and other paintings of India by Sarkis Katchadourian, of New York City.

Freer Gallery of Art.—Additions to the collections included Chinese bronzes, ceramics, jade, and painting; Japanese lacquer and painting; and one Armenian manuscript. Much of the time of the staff was devoted to war work for several Government agencies, including Japanese translations, compilation of a glossary of Chinese geographical and topographical terms, and the examination of Japanese documents. The Director attended a meeting in New York of the Committee of the American Council of Learned Societies on Protection of Cultural Treasures in War Areas. Visitors to the Gallery totaled 62,462 for the year. Fifteen groups received instruction by staff members.

Bureau of American Ethnology.—Emphasis on activities concerned with Latin America has continued during the year. Dr. M. W. Stirling, Chief of the Bureau, directed the Sixth National Geographic Society-Smithsonian Institution expedition to Mexico, locating several new archeological sites in southern Veracruz, Tabasco, and Campeche. Dr. J. R. Swanton read the proof of his extensive work on "The Indians of the Southeastern United States," and completed a manuscript on the much discussed Norse expeditions to America.

Dr. Swanton retired at the end of the year after 44 years of service. In continuation of his studies of Indian languages, Dr. J. P. Harrington discovered evidence that the two South American languages Quechua and Aymara are related to the Hokan of western North America, the first time a linguistic relationship between North and South America has been indicated. Dr. F. H. H. Roberts, Jr., investigated a prehistoric Indian burial near Abilene, Tex., his studies indicating that the burial was made about 10,000 years ago. Dr. Roberts also assembled and edited a manual, "Survival on Land and Sea," which was prepared for the Navy by the Ethnogeographic Board and the staff of the Smithsonian Institution. Dr. J. H. Steward continued work on the Handbook of South American Indians. He was appointed Director of the Institute of Social Anthropology, an autonomous unit of the Bureau reporting to the Secretary, on September 1, 1943. Dr. Alfred Métraux, of the Bureau staff, was appointed Assistant Director of the above Institute on September 18, 1943. Dr. H. B. Collins, Jr., served as Assistant Director of the Ethnogeographic Board, conducting researches connected with regional and other information requested by the Army, Navy, and war agencies. Dr. W. N. Fenton served as research associate of the Board and participated in a survey of area and language teaching in the Army Specialized Training Program and the Civil Affairs Training Schools in American universities and colleges. Dr. H. G. Barnett, who joined the Bureau staff in December 1943, served as executive secretary of a committee formed under the sponsorship of the Ethnogeographic Board for the purpose of assembling data upon the existing state of our scientific knowledge of the Pacific island area. Miss Frances Densmore, a collaborator of the Bureau completed a manuscript on "Omaha Music." The Bureau published its Annual Report and six Bulletins during the year.

International Exchanges.—The International Exchange Service acts as the official agency of the United States Government for the interchange of governmental and scientific publications between this country and all other countries. The total number of packages of such material handled during the fiscal year was 407,764, weighing 243,180 pounds. Shipments to foreign countries continued to be greatly curtailed by war conditions. All countries in the Western Hemisphere received shipments as usual, but in the Eastern Hemisphere, the only countries to which shipments could be made were Great Britain and Northern Ireland, Portugal, the U. S. S. R., Union of South Africa, India, Australia, and New Zealand. In normal times 93 sets of United States official publications are sent abroad through the Exchange Service. At present, however, only 58 sets can be sent, the other 35 sets being held until after the war.

National Zoological Park.—In spite of expected difficulties in obtaining food and supplies and those resulting from manpower shortages, the Park and the animal collection were maintained in good condition and continued to be used and appreciated by large numbers of visitors. The total for the year reached 1,803,532, including a large proportion of service personnel. Many requests for information on biological problems were received from the Army and Navy and other Government agencies, and numerous schools and medical and other groups came to study the collections. Very few animals could be obtained by purchase, but a number of desirable specimens were received by exchange and as gifts from Army personnel and others interested in the Park. Births and hatchings at the Park totaled 78 mammals, 180 birds, and 126 reptiles. Losses by death included the African rhinoceros, the maned wolf, and other animals, birds, and reptiles, including a large python that measured well over 25 feet in length and weighed 305 pounds. At the close of the year the collection totaled 2,626 animals representing 696 species and subspecies.

Astrophysical Observatory.—In the division of astrophysical research, secret war research problems occupied most of the time of two members of the staff; the other members were engaged in reducing and determining the statistical correction for the solar-constant work of the three Smithsonian observing stations at Montezuma, Chile, Table Mountain, Calif., and Tyrone, N. Mex., since 1939. Most of the Director's work consisted in the study of solar-constant variation and associated solar changes in connection with the weather, resulting in the publication of a paper entitled "Weather Predetermined by Solar Variation." As unusual weather conditions are expected during the coming year following a predicted depression of the solar constant, every effort was made to keep the three observing stations in operation. In spite of manpower shortages, this was accomplished by the assistance of the wives of the field directors in observing and computing. In the division of radiation and organisms, the staff was occupied mainly with war research projects.

THE ESTABLISHMENT

The Smithsonian Institution was created by act of Congress in 1846, according to the terms of the will of James Smithson, of England, who in 1826 bequeathed his property to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." In receiving the property and accepting the trust, Congress determined that the Federal Government was without authority to administer the trust directly, and, therefore, constituted an "establishment" whose statutory members are "the President, the

Vice President, the Chief Justice, and the heads of the executive departments."

THE BOARD OF REGENTS

The Board suffered the loss by death of one member, Senator Charles L. McNary, of Oregon, who died on February 25, 1944. He had served as a Senatorial regent since January 23, 1935.

The roll of regents during the fiscal year was as follows: Harlan F. Stone, Chief Justice of the United States, Chancellor; Henry A. Wallace, Vice President of the United States; members from the Senate—Alben W. Barkley, Bennett Champ Clark; members from the House of Representatives—Clarence Cannon, Foster Stearns, Edward E. Cox; citizen members—Frederic A. Delano, Washington, D. C.; Roland S. Morris, Pennsylvania; Harvey N. Davis, New Jersey; Arthur H. Compton, Illinois; Vannevar Bush, Washington, D. C.; and Frederic C. Walcott, Connecticut.

Proceedings.—The annual meeting of the Board of Regents was held on January 14, 1944. The regents present were Chief Justice Harlan F. Stone, Chancellor; Vice President Henry A. Wallace; Representatives Clarence Cannon, Foster Stearns, and Edward E. Cox; citizen regents Frederic A. Delano, Roland S. Morris, Harvey N. Davis, Arthur H. Compton, and Vannevar Bush; and the Secretary, Dr. Charles G. Abbot.

The Secretary presented his annual report covering the activities of the parent Institution and of the several Government branches, and including the financial report of the executive committee, for the fiscal year ended June 30, 1943, which was accepted by the Board. The usual resolution authorizing the expenditure by the Secretary of the income of the Institution for the fiscal year ending June 30, 1945, was adopted by the Board.

The Secretary stated that in order that the employees paid from Smithsonian funds might share the same liberalized retirement advantages as the Government-paid employees in the Institution, a bill covering this matter (S. 1558) had been introduced by Senator Barkley and referred to the Senate Committee on the Civil Service.

Owing to the exigencies of wartime travel, the annual meeting of the Smithsonian Art Commission, usually held in December, was again omitted.

The Board formally ratified certain resolutions adopted by a mail vote authorizing the Secretary to execute an indenture dated March 31, 1943, by Samuel H. Kress and the Samuel H. Kress Foundation modifying and amending an indenture dated June 29, 1939, by the same parties, and further authorizing the Secretary to accept the offer of additional art objects by these parties for the collections of the National Gallery of Art.

A resolution was adopted providing for the appointment of committees to handle matters connected with the proposed celebration in 1946 of the centenary of the founding of the Institution.

In his special report the Secretary outlined to the regents some of the more important wartime activities carried on by the Institution and its several branches.

FINANCES

A statement on finances will be found in the report of the executive committee of the Board of Regents, page 110.

TWELFTH ARTHUR LECTURE

Under the terms of the will of the late James Arthur, of New York, the Smithsonian Institution received in 1931 a fund, part of the income from which should be used for an annual lecture on some aspect of the science of the sun.

The twelfth Arthur lecture was given by Secretary C. G. Abbot on February 29, 1944, under the title "Solar Variation and Weather." The lecture will be published with illustrations in the Report of the Smithsonian Institution for 1944.

The 11 previous Arthur lectures have been as follows:

1. The Composition of the Sun, by Henry Norris Russell, professor of astronomy at Princeton University. January 27, 1932.
2. Gravitation in the Solar System, by Ernest William Brown, professor of mathematics at Yale University. January 25, 1933.
3. How the Sun Warms the Earth, by Charles G. Abbot, Secretary of the Smithsonian Institution. February 26, 1934.
4. The Sun's Place among the Stars, by Walter S. Adams, director of the Mount Wilson Observatory. December 18, 1934.
5. Sun Rays and Plant Life, by Earl S. Johnston, assistant director of the division of radiation and organisms, Smithsonian Institution. February 25, 1936.
6. Discoveries from Eclipse Expeditions, by Samuel Alfred Mitchell, director of the Leander McCormick Observatory, University of Virginia. February 9, 1937.
7. The Sun and the Atmosphere, by Harlan True Stetson, research associate, Massachusetts Institute of Technology. February 24, 1938.
8. Sun Worship, by Herbert J. Spinden, curator of American Indian Art and Primitive Culture, Brooklyn Museums. February 21, 1939.
9. Solar Prominences in Motion, by Robert R. McMath, director of the McMath-Hulbert Observatory of the University of Michigan. January 16, 1940.
10. Biological Effects of Solar Radiation on Higher Animals and Man, by Brian O'Brien, professor of Physiological Optics, University of Rochester. February 25, 1941.
11. The Sun and the Earth's Magnetic Field, by John A. Fleming, Department of Terrestrial Magnetism, Carnegie Institution of Washington. February 26, 1942.

PUBLICATIONS

The Institution's publication program has again emphasized material pertaining to the war or to Latin America as a part of its endeavor to make every phase of its activities serve a useful wartime purpose.

The papers in the series Smithsonian War Background Studies continued to be in great demand, particularly from Army and Navy organizations and personnel. Seven numbers were issued during the year—Nos. 13 to 19—and No. 20, on China, appeared soon after the close of the year. A list of these, as well as other publications of the year, will be found in appendix 10. The demand for the War Background papers continued to increase until it became necessary to make a charge for copies requested by civilians and for large lots of copies ordered by service organizations, while continuing the free service distribution of single copies and small lots. Soon after the close of the year the total number of copies of Nos. 1-20 printed by the Institution had reached 203,500, and 211,525 additional copies have been ordered for the Army and Navy, a grand total of nearly half a million books.

A pocket-size field collectors' manual was published with the aim of providing a worth-while activity for service personnel stationed in areas not actually in the fighting zones. The manual gives detailed directions for preparing, preserving, and packing specimens of animals, plants, and minerals. This book also is given free to service personnel and sold to civilians.

In the Miscellaneous Collections series, a paper intended chiefly for the use of medical officers was issued under the title "The Feeding Apparatus of Biting and Disease-carrying Flies: A Wartime Contribution to Medical Entomology," by R. E. Snodgrass. Several hundred copies were made available to Army and Navy medical personnel. Also for use in connection with wartime medical problems in the Pacific theater, it was necessary to reprint an edition of a previous paper, "Molluscan Intermediate Hosts of the Asiatic Blood Fluke, *Schistosoma japonicum*, and Species Confused with Them," by Paul Bartsch.

Many papers in all series of Smithsonian publications dealt with studies in biology and anthropology of the other American republics, as a part of the Government's program of improving cultural relations between the Americas. In the Miscellaneous Collections a survey of existing archeological knowledge of the Andean region appeared under the title "Cross Sections of New World Prehistory: A Brief Report on the Work of the Institute of Andean Research, 1941-1942," by William Duncan Strong. The Smithsonian Annual Report included a comprehensive paper on the "Past and Present Status of the Marine Mammals of South America and the West Indies," by

Remington Kellogg. National Museum publications included a number of Proceedings papers on various phases of biology in Latin America and a Bulletin entitled "Checklist of the Coleopterous Insects of Mexico, Central America, the West Indies, and South America," parts 1 and 2, by Richard E. Blackwelder. This last will be an essential tool for all future entomological work in Latin America. In the series Contributions from the United States National Herbarium appeared "Taxonomic Studies of Tropical American Plants," by C. V. Morton. The Bureau of American Ethnology published four Bulletins on the archeology of Mexico, among them one entitled "Stone Monuments of Southern Mexico," by Matthew W. Stirling.

The total number of publications issued during the year was 67, and 172,027 copies of the various series were distributed.

LIBRARY

The Smithsonian library has been increasingly used by the Army, Navy, and war agencies. In the Museum branch library alone, 520 requests for information from these sources were recorded. The branch libraries of the Bureau of American Ethnology and the Astrophysical Observatory were also frequently called upon, and the staff of the Ethnogeographic Board used all the branch libraries in search of material needed to aid the armed services and war agencies. Through the Library of Congress, the Smithsonian library is co-operating with the American Library Association in collecting material to aid libraries in war areas. The gradual decline in the receipt of publications from abroad has continued, but domestic scientific series showed very little decline. Changes in library procedure shortened the interval between the receipt of new publications and their availability for use. Statistics of the year's activities show 194 new exchanges arranged, 4,422 "wants" received, 6,673 volumes and pamphlets cataloged, 11,360 books and periodicals loaned, and 1,683 volumes sent to the bindery.

Respectfully submitted.

C. G. ARBOT, *Secretary.*

APPENDIX 1

REPORT ON THE UNITED STATES NATIONAL MUSEUM

SIR: I have the honor to submit the following report on the condition and operation of the National Museum for the fiscal year ended June 30, 1944.

Appropriations for the maintenance and operation of the National Museum for the year totaled \$929,999, which was \$37,369 more than for the previous year.

THE MUSEUM IN WARTIME

Visitors during the year numbered 1,532,765, an increase of 177,496 over those of the previous fiscal year; approximately 40 percent of all visitors were men and women in uniform.

Although the possibility of enemy attack on Washington became steadily less, measures for safeguard of visitors, collections, and buildings were continued in force. The air-raid defense organization remained in operation under the direction of the general defense coordinator, F. M. Setzler, head curator of anthropology. Collections removed from the buildings as a precaution against enemy attack were inspected regularly, and careful guard was maintained over them.

As a result of a recommendation by the Smithsonian War Committee a free guide service through the National Museum for members of the armed forces was arranged through the U. S. O. groups of Washington. Under the direction of F. M. Setzler a route was established within the Natural History building and a script was prepared describing the exhibits selected for the tour. Classes for instructing the volunteer hostesses were held on Sunday afternoons from August 22 to October 17, 1943, and during February 1944. On October 24 the first U. S. O. guide service for men and women in uniform was inaugurated. Tours were conducted each Sunday at 15-minute intervals from 11 a. m. to 3:30 p. m. Each tour required approximately 45 minutes. From October 24, 1943, to June 25, 1944, 5,325 military visitors were escorted through the building. Credit for the success of this service is due to the excellent cooperation of U. S. O. headquarters, to the chairman and head receptionist, Miss Margaret Bledsoe, and to other U. S. O. hostesses.

Requests for information from the various war agencies continued to come to the staff during the year, and numerous war services were rendered by most of the laboratories and by many individuals on the staff.

Dr. Remington Kellogg, curator of mammals, served as chairman of the American delegation at the International Conference on the Regulation of Whaling in London during January 1944. At the request of the National Research Council, Dr. Kellogg prepared text, keys, distribution maps, and illustrations of monkeys known to be susceptible to infection by malarial parasites to aid in studies of malaria in man. Other services provided by the personnel of the division of mammals to officers of special Army and Navy units and other agencies concerned with the war included the furnishing of information relative to the distribution and identification of mammals involved in the transmission of diseases. Herbert G. Deignan, associate curator of birds, assisted in work on maps and on geographic names of the Far East and in a compilation of literature dealing with parts of that area. Dr. Doris Cochran, associate curator of reptiles and amphibians, assisted the Surgeon General's Office in the preparation of lists of Asiatic reptiles. Personnel of the division of fishes furnished information in response to numerous inquiries relative to dangerous, poisonous, and useful fishes, methods of fishing, sound-making fishes, and emergency fishing equipment. Many identifications were made in the division of insects, particularly of mosquitoes, mites, and ectoparasites, and information was supplied on the habits of these forms, at the request of the Army and Navy. About 1,200 specimens of insects and Acarina were specially mounted on pins and approximately 450 slide mounts were made for use in Army and Navy training centers throughout the country in training programs in which health problems are involved. In addition, nearly 200 officers assigned to malaria survey or control units, or to similar activities, received instructions or other help from personnel of the division, and information on the disease-bearing insects of specific foreign areas was furnished the Division of Medical Intelligence of the Surgeon General's Office. At the request of the National Research Council, Dr. Paul Bartsch, curator of mollusks, served as a member of a committee charged with the preparation of a list of helminth parasites of the Southwest Pacific and their intermediate hosts. Dr. E. H. Walker, assistant curator of plants, prepared an account of the emergency food plants of the Tropics. Paul S. Conger, associate curator of the section of diatoms, studied samples of material involved in the fouling of ships, mines, and other marine structures. He likewise prepared a bibliography of literature concerning the value of plankton as food.

Services of the department of anthropology dealt with a wide variety of subjects relating to people in the Caribbean islands, Pacific and Indonesian areas, Oceania, Micronesia, Burma, Japan, China, the Philippine Islands, Central America, Europe, and Africa. The information furnished included suggestions for Tropical and Arctic clothing, and footgear for aviators, water supply, population, primitive weapons, house types, degree of western influence, physical characteristics, and leather products. The collections of the division were used in a study of the resources of particular strategic geographical areas with a view to conservation of shipping space. Dr. T. Dale Stewart was granted a 6-month furlough to teach anatomy to Army and Navy medical students at the Washington University School of Medicine in St. Louis, Mo. Dr. Waldo R. Wedel, associate curator of archeology, was detailed for special services to the Military Planning Division, Office of the Quartermaster General, War Department, from September 1943 to March 1944. The division of physical anthropology supplied the Office of Strategic Services with photographs of various eastern physical types. It also supplied detailed data on average body weights of Europeans and various peoples of the Far East to the Office of the Quartermaster General.

In the department of geology, two members of the staff, in cooperation with the Geological Institute of Mexico, have continued field studies in the economic geology of that country as a part of the war effort. Curator W. F. Foshag spent the year on detail from the Museum in a continuation of the supervision of surveys for strategic minerals in Mexico. Dr. G. A. Cooper, similarly, spent 3 months in the field in Sonora concluding studies begun last year on the stratified rocks. The results, soon to be published, will be useful in the location of new mineral areas. Dr. Cooper also concluded field work on the project dealing with the subsurface geology of the Devonian rocks of Illinois, obtaining information for use in the oil development of that and neighboring States.

Members of the geological staff in the home office have been more occupied than ever before in furnishing information to the various war agencies. These services have included such diverse items as the preparation of analyses, assisting in selecting and grading calcite for the War Production and other Boards, editing a scientific volume for an allied country, and furnishing information of all kinds to an ever-increasing number of service men and women visiting the Museum.

Other services, especially from the department of engineering and industries, have included the following:

Construction of two demonstration models of new ordnance devices for the National Inventors' Council; transfer of a series of model

buildings to the War Department, Corps of Engineers, Camouflage Section; information on revolving airfoils to the Technical Data Laboratory, Wright Field, Dayton, Ohio; furnishing photographs for Navy training films; identification of woods; also information on properties and uses of woods for Navy Department, War Production Board, Foreign Economic Administration, and Inter-American Development Commission; methods of preserving specimens of dehydrated foods for War Food Administration; advice on disposition of hemp produced in Kentucky to Commodity Credit Corporation; assistance in drawing up contract specifications involving a true lock-stitch in sewing safety seams, to United States Maritime Commission; suitability of palmyra fiber as a substitute for rattan for stiff brushes to the Navy Department; and aid in the training of document inspectors of Federal Bureau of Investigation in identification of various printing processes.

COLLECTIONS

Accessions for the year numbered 1,159 separate lots, totaling 239,640 specimens. This was an increase over those received last year of 9,409 specimens, but a decrease of 18 in the number of accessions. Specimens were accessioned by the five departments as follows: Anthropology, 852; biology, 229,546; geology, 3,466; engineering and industries, 1,388; history, 4,388. Most of the accessions were gifts from individuals or specimens transferred from other Government agencies. The more important of these are summarized below. Catalog entries in all departments now total 18,098,775.

Anthropology.—The division of archeology received an important gift of 115 lots of potsherds and other materials from various Indian sites, many of which are on or near the presumed route of De Soto's expedition of 1539-42 through the southeastern United States. Two gold-and-silver book ends, reflecting the Tiahuanacan style of architecture and sculpture, were presented by Vice President Henry A. Wallace, who received them as gifts from the Chamber of Commerce in Bolivia, on the occasion of his visit to La Paz. The division of ethnology was presented with a documented collection (159 specimens) pertaining to the Huichol Indians of northern Jalisco. Two other important collections received by the division were 26 oil portraits of Navaho, Apache, and Pueblo Indians of Arizona and New Mexico, painted by Carl Moon, and an assemblage of excellent examples of Moro and Indonesian brasses and Philippine metalwork, which had been presented to the late President and Mrs. William Howard Taft, during their residence in the Philippines.

Biology.—The largest single collection received by the division of mammals in the past 25 years consisted of about 2,400 specimens from

Colombia, collected by Philip Hershkovitz during his tenure of the Walter Rathbone Bacon Traveling Scholarship of the Smithsonian Institution. From the Fish and Wildlife Service came by transfer the year's second-largest mammalian accession, 624 mammals from various North American localities. A beaked whale foetus, about 7 feet long, the largest in the National collections, is also notable.

As in the division of mammals, the largest accession of the year to the division of birds came from Colombia. This collection comprised 3,281 specimens, sufficient to give the Museum a reasonably complete representation of the bird life of northeastern Colombia. A smaller avian collection, 85 specimens, also from Colombia, represents localities not included in the larger collection first mentioned. Another collection included 20 species of birds hitherto unrepresented in the study series.

As a result of exchanges with other institutions, several species of reptiles and amphibians hitherto unrepresented or poorly represented in the Museum have been added to the collections. Specimens from the Great Smoky Mountains National Park, Jamaica, and Honduras were received, and 60 turtles, lizards, snakes, and frogs were contributed by Philip Hershkovitz, through the Walter Rathbone Bacon Traveling Scholarship.

Exchanges consummated during the year brought much valuable material, including 321 cotypes, to the division of fishes. Smaller ichthyological collections, received as gifts, also included type material and some specimens from type localities not previously represented in the National collections.

The vital and significant role played by entomology and entomologists in the war is reflected in the host of mosquitoes and mosquito larvae received from the sanitary and medical corps of the armed forces—more than 10,000 specimens. About 67,000 bees, butterflies, and insects, including some holotype and paratype material, came as gifts and by transfer from other Government departments.

Seven of the year's accessions in the division of marine invertebrates included type material. Especially noteworthy is the fact that during the past year seven accessions, totaling 2,380 specimens, many of them rare, were collected and donated to the Museum by men in the armed forces.

The collection of Mexican land shells in the division of mollusks was materially enhanced by three gifts, totaling 1,490 specimens. The largest known single collection of Jamaican representatives of the molluscan family Neritidae, consisting of 51,000 specimens and accompanying 850 microscopic slides, came as a gift.

Several valuable accessions in the form of types and cotypes came to the helminthological collections as gifts. These included species of

the genera *Ochoterenella*, *Choledocystus*, *Choricotyle*, *Diphyllobothrium*, *Hexostoma*, *Cyclocotyla*, and *Raillietina*.

Among the 89 echinoderms accessioned were 6 undescribed species, 6 paratypes of new ophiurans, and 2 interesting abnormal starfishes.

Outstanding among the 36,240 plants received during the year was the Chickering herbarium of approximately 10,550 specimens. This herbarium, formed by the late John White Chickering, Jr., is a valuable addition as it includes material of historical importance from collections not at all or scantily represented previously. Also included are numerous specimens from the District of Columbia, of which many were collected in plant habitats now destroyed. Most of the smaller collections received came from South American or West Indian localities. Of special importance among these were about 2,500 specimens of bamboos, including an unusually good representation of vegetative structures important to the field identification of the bamboos.

The Albert Mann diatom collection, consisting of approximately 8,000 slides of mounted specimens, more than 10,000 samples of crude diatom material, and over 200 negatives and 300 lantern slides, transferred from the Carnegie Institution of Washington, was formally accessioned during the year. In combination with the other material this makes the Museum collection of diatoms one of the most important in the world.

Geology.—Income from the Roebling fund, provided for the purchase of important gems and minerals, was used to procure 31 gem stones of rare quality and high exhibition value and 2 mineral accessions, consisting of 4 unusually formed quartz crystals and 8 transparent colorless scheelites. A beautiful pink Brazilian topaz of 34.1 carats was acquired through the Frances Lea Chamberlain fund, and the Canfield endowment fund provided two specimens of libethenite and a covellite. Several important single accessions came as the result of the associate curator's efforts to interest people in making collections for the Museum. By transfer from another Government department the division of mineralogy and petrology received specimens of weinschenite (yttrium phosphate), representing the first occurrence of this rare mineral in the United States.

Seven new meteorites were added to the collection, six of them being undescribed falls.

The largest addition to the ore collection consisted of a series of manganese and chromium ores from world-wide foreign deposits.

The most important new material received by the division of invertebrate paleontology and paleobotany consisted of 500 specimens of rare Paleozoic fossils collected by the curator during his field work in northwestern Sonora, Mexico.

Plaster casts of type fossils today have great scientific value, in view of the destruction taking place in foreign museums. Such a cast, an important English Carboniferous crinoid, the holotype and only specimen of which was in the ill-fated Bristol Museum, was received as a gift. Numerous types and holotypes of foraminifers, bryozoans, mollusks, echinoids, cephalopods, and corals were welcome additions to the collection. Important among the acquisitions of specimens of fossil vertebrates was a composite skeleton of an extinct antelope, as well as casts of the following: Complete skull of a curious three-horned antelope; type specimen of a flying reptile; and skeleton of a rare Triassic armored reptile. The ichnite collection was enriched by nine slabs containing the trails of *Paramphibius didactylus*, once considered a vertebrate animal but now regarded as a horseshoe crab.

Engineering and industries.—From the standpoints of historical merit and of popular appeal first honors among the acquisitions of the year in this department are bestowed upon two automobiles. One of these is a U. S. Army $\frac{1}{4}$ -ton, 4 x 4 truck, one of the first of 62 of these vehicles built in 1940, and the prototype of these vehicles made famous by World War II. The other is a Winton, 1903, the first automobile to be driven across the United States, a trip that required 63 days on the road. Outstanding among the gifts to the watercraft collection was an original kerosene-burning brass bulk-head lantern of the first S. S. *Mauretania*, 1907-37, presented by President Franklin D. Roosevelt. The lantern now stands in the exhibition case containing the handsome model of this famous vessel presented to the Museum by the President several years ago.

Through the Textile Color Card Association of the United States, the textile section received the ninth edition of the Standard Color Card, with its two supplements, the United States Arms and Services Color Card and the United States Army Standard Thread Card. The Association is supported by textile manufacturers and representative firms of almost every industry using color. These firms agree to have their products match the colors included in the official standard card, resulting in a great saving of time to consumers in obtaining exact shades of colors in materials that are to be used together. This standardization is especially valuable to the United States Arms and Services, each service having an official color requirement for its uniforms, trimmings, badges, and similar equipment. The Standard Thread Card is furnished by the Quartermaster General's office to quartermaster depots and contractors making clothing or equipage for the United States Army.

An important accession in the section of chemical industries was an exhibit illustrating the chemistry and applications of refined alpha-

cellulose derived from wood pulp. Since the military services' requirements for ordnance purposes cover practically all the annual production of cotton linters, the manufacturers of rayon found it necessary to turn to alpha-cellulose for their raw material. The applications of the wood-pulp cellulose shown in the exhibit include rayon, molded and laminated plastics, cellophane, artificial leather, rayon tire-cord fabric, and electric-arc welding rods.

An interesting addition to the collection of commercial furs was a gift from Vice President Henry A. Wallace of two robes made from strips of vicuña skins. The robes were presented to him by Miss Rosa Prado, daughter of the President of Perú, on the occasion of Mr. Wallace's good-will tour.

In the division of medicine and public health the most valuable items were added to the section of pharmacy. These included a complete exhibit illustrating the manufacture and use of dried blood plasma now effectively employed by our armed forces; a series of objects picturing the method of obtaining penicillin, the recently discovered miracle-performing bacteriostatic drug; and a collection outlining the life history of Carl Wilhelm Scheele, the internationally famous apothecary. To the history of medicine section was added the first portable X-ray machine known to have been operated successfully on a battlefield.

The outstanding accession in the section of graphic arts was a French color print of the eighteenth century, "L'Amant Surpris," by C. M. Descourtis after F. Schall. This type of print, the *estampe galante*, is highly prized and much sought after by collectors. Descourtis was one of the important engravers of the period, and it is said that "L'Amant Surpris" is one of his masterpieces. Walter Tittle, a well-known drypoint artist, presented the section with 19 examples of his work, following his special exhibition in the Museum. VOKS, the Soviet Russian Society for Cultural Relations with Foreign Countries, gave the section six war posters produced by the hand-stencil process. No printing equipment is necessary in making posters of this kind, which the Russians have developed to a high degree. Guerrilla artists have used this method extensively in occupied territories where the absence of printing and transportation facilities eliminates other methods.

History.—The collection of civil, naval, marine, and military medals and decorations was increased by specimens of several awards of these types established during the present war. Among these were specimens of the Air Medal, awarded to members of the armed forces of the United States who have distinguished themselves since September 8, 1939, by meritorious achievement in flight. It is second only to the Distinguished Flying Cross. They include also specimens of

the decorations representing the four degrees of the Legion of Merit, namely, Chief Commander, Commander, Officer, and Legionnaire. These decorations are for award to the personnel of armed forces of the United States and the Philippines, and of the armed forces of friendly foreign nations. The recipients must have distinguished themselves by exceptionally meritorious conduct in the performance of outstanding services since the Presidential proclamation of emergency, September 8, 1939. These decorations are the first to be founded by the United States Government for award to foreigners. Other specimens illustrate the Merchant Marine Distinguished Service Medal and the Mariner's Medal. The first of these was established for award to any person in the American Merchant Marine who on or after September 3, 1939, "has distinguished himself * * * in the line of duty." The second is awarded to any seaman who, while serving on a ship during the war period, is wounded, suffers physical injury, or suffers through dangerous exposure as the result of an act of an enemy of the United States.

The collection of uniforms was increased by the addition of several United States Army and United States Military Academy uniforms of the early part of the twentieth century. Uniforms of the types worn by Army nurses and officers and members of the Women's Army Corps were received from the War Department. A series of German and Japanese uniforms captured in Italy and the Aleutian Islands was received as a loan from the War Department.

An interesting gift to the philatelic collection was a series of Aguinaldo (Philippine) stamps totaling more than 2,000 specimens. A cover franked with a 2-cent red Aguinaldo stamp postmarked Bataan, the locality famous for the valiant fight against the Japanese of the American forces under the leadership of Gen. Douglas MacArthur, is included. Among the stamps transferred by the Post Office Department was a special series of 12 United States stamps commemorating the European countries that have been overrun and occupied by the Axis powers—Albania, Austria, Belgium, Czechoslovakia, Denmark, France, Greece, Luxembourg, Norway, The Netherlands, Poland, and Yugoslavia. Each stamp bears in color the national flag of the country concerned. The Soviet Union presented a 30-kopeck and a 3-ruble stamp showing the Russian, British, and American flags, commemorating the recent historic conference at Tehran. Among the stamps emanating from enemy countries that found their way into the Museum collections were 2 Japanese stamps commemorating the fall of Bataan and Corregidor, 11 stamps issued by the Japanese military authorities for use in the occupation of the Dutch Indies, and 14 varieties of Japanese stamps for the army of

occupation in the Philippine Islands. A large number of German stamps also were received.

EXPLORATIONS AND RESEARCH

Although field explorations for the year were concerned principally with the conduct of the war, important research was accomplished along many other collateral lines.

Anthropology.—During his assignment as teacher of anatomy to Army and Navy medical students at Washington University School of Medicine, St. Louis, Mo., studies were carried on by the curator, Dr. T. Dale Stewart, on age and sex changes in the human skeleton. This was possible because the skeletal collections preserved in the university's department of anatomy were obtained from the dissecting rooms and therefore were accurately identified. During the course of this work Dr. Stewart took the opportunity also of studying arthritic changes in the skeleton. Since arthritis is closely correlated with age, it was hoped that the university's identified material would aid in the interpretation of the condition in the groups in the Museum collections where exact age is unknown. In addition to his work at the university, Dr. Stewart spent some time in studying Indian skeletons excavated in Illinois by Dr. P. F. Titterington, a St. Louis physician. Two cultural horizons are represented by these Indian remains, the Hopewell and the Jersey County bluff focus of the Middle Mississippi.

Up to the time of his death on September 5, Dr. Aleš Hrdlička continued the work of analyzing his data on the human tibia. The year also saw the publication by the Museum of the seventh and last part of Dr. Hrdlička's "Catalog of Human Crania in the United States National Museum Collections," a work on which he had been engaged for many years. The final part covers the non-Eskimo people of the Northwest Coast, Alaska, and Siberia and includes measurements of all skulls of this provenience deposited in the National Museum as well as of many supplementary ones in various Russian institutions. The entire series of catalogs presents measurements of more than 7,500 non-White crania and has been described as constituting "one of the most valuable sources of basic anthropometric data in existence."

Biology.—Under the auspices of the Division of Cultural Relations of the Department of State, Ellsworth P. Killip, associate curator of plants, visited Colombia during April, May, and June for consultations and work in botanical centers in Bogotá and Cali. In working over the Museum's South American material, which includes large recent collections of plants, as well as a considerable accumulation of

specimens received for identification in the past, Mr. Killip assembled much valuable data for the proposed "Flora of Colombia."

Philip Hershkovitz, holder of the Walter Rathbone Bacon Scholarship for 1941-43, returned from Colombia in October, after an absence of almost 2 years. The collection he amassed forms the largest single accession of mammals received by the Museum during the past 25 years.

Under the W. L. Abbott fund, M. A. Carriker, Jr., continued ornithological field work in Colombia until October. He brought to the Museum the results of two seasons' work, one of the finest collections of birds that has ever been made in that area.

Dr. Remington Kellogg, curator of mammals, served as chairman of the American delegation to the International Conference on the Regulation of Whaling held in London during January. Between sessions of the conference he studied at the British Museum in preparation of a report on the recent porpoises. Dr. Kellogg spent part of September at the Museum of Comparative Zoölogy examining a collection of cetacean remains from Polk County, Fla. Also, at the request of the National Research Council, for the Board for the Coordination of Malarial Studies, in collaboration with Major E. A. Goldman of the Fish and Wildlife Service, Dr. Kellogg prepared the first of a series of descriptive accounts of the kinds of monkeys that may carry malarial infections.

The curator of birds, Dr. Herbert Friedmann, completed part 10, the gallinaceous birds, of Ridgway's unfinished monograph, "The Birds of North and Middle America," and began the revision of his own previously completed manuscript on the falconiform birds. H. G. Deignan, associate curator of birds, completed his monograph on "The Birds of Northern Thailand," now in press.

The associate curator of reptiles, Dr. Doris M. Cochran, reports further substantial progress in her studies on South American frogs. She also undertook to expand her popular handbook on "Poisonous Reptiles," Number 10 of the Smithsonian War Background Studies, into a treatise on "Dangerous Reptiles," nonpoisonous, as well as poisonous, for the general appendix to the Smithsonian Annual Report.

Dr. Paul Bartsch, curator of mollusks, has worked in close cooperation with a special committee of the National Research Council, in preparing a list of known or suspected molluscan intermediate hosts of human parasites.

In connection with the preparation of survivor manuals, Dr. L. P. Schultz, curator of fishes, and Earl D. Reid, scientific aid, demonstrated to members of the U. S. Navy the use of derris root for securing fish for food in emergencies.

Dr. Schultz also made notable progress with his studies on the extensive material that he collected in Venezuela, finishing a report on the Characinidae and completing manuscript for the families Gymnotidae, Cichlidae, Cyprinodontidae, Dasyatidae, Tetrodontidae, and Centropomidae.

The curator of insects, Dr. E. A. Chapin, made further progress with the manuscript embodying the results of his investigations on the beetle genus *Hippodamia* and continued work on other sections of the Coccinellidae.

Dr. R. E. Blackwelder, associate curator of insects, continuing his work on Bulletin 185 of the National Museum, "Checklist of the Coleopterous Insects of Mexico, Central America, the West Indies, and South America," submitted the manuscript for part 3. Parts 1 and 2 were published during the year.

Austin H. Clark, curator of echinoderms, completed part 4 of Bulletin 82, "Monograph of the Existing Crinoids," except for assembling the plates. He also published "Iceland and Greenland," the fifteenth of the Smithsonian's War Background Studies, and, in collaboration with Dr. E. H. Walker, assistant curator of plants, prepared material for the biological section of another volume of this series dealing with the Aleutian Islands.

All divisions in the department contributed to the Navy's "Survival on Land and Sea," published in December, to "A Field Collector's Manual in Natural History," recently issued by the Smithsonian, and to the preparation of nine mimeographed leaflets for distribution to correspondents inquiring about the animal and plant life of the Southwest Pacific.

Geology.—As in the other departments of the Museum, several members of the staff of the department of geology are on military detail. The researches of the head curator, Dr. R. S. Bassler, have been limited to three projects; first, his monographic study of Lower Paleozoic corals; second, a paper on the giant Paleozoic Ostracoda known as the Leperditidae; and third, a continuation of researches on American Ordovician crinoids and cystids contained in the Springer collection. The manuscript and illustrations of all three have been more than half completed.

Curator William F. Foshag was occupied the entire year in Mexico with his supervisory work for the Geological Survey in surveys for strategic minerals. In addition, he spent some time at the Parícutin Volcano making observations and collecting material for the Museum exhibition series.

E. P. Henderson completed several analyses of new meteorites. "The Metallography of Meteoric Iron," a monograph by Dr. Stuart H.

Perry, associate in mineralogy, was published during the year as a Bulletin of the National Museum.

Dr. G. A. Cooper, in collaboration with Prof. A. S. Warthin, of Vassar College, completed his survey of Illinois Devonian oil strata, and, in collaboration with the Instituto Geológico de México, continued field and laboratory studies of the geology of northwestern Sonora. A month and a half of field work in Sonora, in association with his Mexican colleague, Ing. A. R. V. Arellano, resulted in noteworthy paleontological collections and considerable increase in knowledge of the structure and stratigraphy of the area.

Under the Walcott fund of the Smithsonian Institution, in collaboration with Drs. Myron N. Cooper and R. S. Edmundson, of the Virginia Geological Survey, Dr. Cooper made an investigation of the relationships of the limestones that occur on the flanks of Clinch Mountain in southwestern Virginia and northern Tennessee.

Before his untimely death Dr. Charles E. Resser was engaged in the study of the Lower Ordovician trilobites of Vermont and adjacent areas and was continuing his Cambrian Summary and Bibliography. Many years of work by Drs. Walcott and Resser have gone into this summary and bibliography, both of which when finished will be valuable contributions to science.

Field work in vertebrate paleontology, usually one of the best sources of striking exhibition material, was necessarily restricted. In a short trip to the nearby Calvert Cliffs on Chesapeake Bay, Curator C. W. Gilmore and his assistants had the good fortune to excavate a sirenian skeleton of Miocene age, a fossil sea cow over 10 feet long.

MISCELLANEOUS

Visitors.—The number of visitors to the Museum buildings during the year showed an increase of 177,496 over the previous year. The total number, 1,532,765, is, of course, far below the peacetime record of 2,408,170 in 1937-38, but the increase does indicate a salutary up-trend in the degree to which the National Museum exhibits and collections are being viewed and studied by the people even in wartime. August 1943 and April 1944 saw the largest number of visitors, 162,016 and 164,221, respectively, being recorded for these months. The attendance in the four Smithsonian and Museum buildings was as follows: Smithsonian building, 301,212; Arts and Industries building, 566,496; Natural History building, 493,239; Aircraft building, 171,818.

Since a considerable proportion of the visitors consisted of men and women in the armed forces, special services were proffered this group and every effort was made to enhance their visits. In the Natural History building a program of Sunday docent service, for guiding

parties through the Museum, was inaugurated. A number of women U. S. O. volunteers were especially trained to act as guides, and the "tours" conducted by them have proved very popular. During the period covering the last 35 Sundays of the fiscal year, over 5,000 members of the military personnel took advantage of this guide service.

Publications and printing.—The sum of \$30,000 was available during the fiscal year for the publication of the Annual Report, Bulletins, and Proceedings of the National Museum. Twenty publications were issued—the Annual Report, 4 Bulletins, 1 Contribution from the National Herbarium, and 14 Proceedings papers. A list of these publications is given in the report on publications, appendix 10.

The distribution of volumes and separates to libraries and individuals on the regular mailing lists aggregated 40,817 copies.

Special exhibits.—Seventeen special exhibits were held during the year in the foyer and adjacent space of the Natural History building, under the auspices of various educational, scientific, recreational, and governmental groups. In addition the department of engineering and industries arranged 28 special displays—5 in engineering, 12 in graphic arts, and 11 in photography.

CHANGES IN ORGANIZATION AND STAFF

There was no major change in the organization of the National Museum, but some work has been done in allocating positions to their proper grades under the Classification Act on the basis of the duties of each position.

Honorary appointments were conferred on Maj. Edward A. Goldman as associate in zoology on August 1, 1943, Dr. Floyd A. McClure as research associate in botany on April 21, 1944, Dr. J. B. Reeside, Jr., as custodian of Mesozoic collection on June 19, 1944, and Clarence R. Shoemaker as associate in zoology on April 1, 1944.

In the department of biology, Dr. David H. Johnson, associate curator, division of mammals, was furloughed for military duty on November 15, 1943, and Dr. Richard E. Blackwelder, associate curator, division of insects, was furloughed temporarily for war work on August 23, 1943. Other changes were the resignation on March 22, 1944, of Walter A. Weber, assistant curator, division of birds; the retirement of Clarence R. Shoemaker, associate curator, division of marine invertebrates, and Julian S. Warmbath, taxidermist. The latter vacancy was filled by the promotion of Watson M. Perrygo on December 9, 1943. In the section of diatoms, Paul S. Conger was appointed associate curator on March 9, 1944.

In the department of geology, Dr. G. Arthur Cooper was advanced to the curatorship of the division of invertebrate paleontology and

paleobotany on October 2, 1943, to succeed Dr. Charles E. Resser, who died on September 18, 1943. Miss Marion F. Willoughby, scientific aid, transferred to the United States Geological Survey on October 31, 1943.

In the department of engineering and industries, Dr. A. J. Olmsted, for a number of years chief photographer of the Museum, was relieved of the duties of that position on November 9, 1943, and was appointed associate curator in charge of the section of photography. Gurney I. Hightower succeeded Dr. Olmsted in charge of the photographic laboratory on January 9, 1944, with Floyd B. Kestner as assistant.

Other changes in the administrative staff during the year were the retirement of Royal H. Trembly, superintendent of buildings and labor, who was succeeded by Lawrence L. Oliver on December 10, 1943. Anthony W. Wilding was appointed property officer on December 21, 1943. The vacancy created by the death of Miss Helen A. Olmsted, personnel officer, was filled by the appointment of Mrs. Bertha T. Carwithen on February 1, 1944; and Mrs. Margaret L. Vinton was appointed personnel assistant on March 9, 1944.

Employees furloughed for military duty during the year were as follows: Robert L. Bradshaw, on October 12, 1943; Joseph R. Burke, Jr., on October 13, 1943; John Carl Carter, on May 5, 1944; Walter McCree, on April 3, 1944; and David H. Johnson on November 15, 1943.

Ernest Desantis returned to duty from military furlough on October 18, 1943.

Eleven persons were retired, three having reached retirement age, five on account of disability, and three by optional retirement, as follows: For age, William Rice, laborer, on September 30, 1943, after 15 years, 3 months of service; Thomas J. Shannon, guard, on April 30, 1944, after 18 years, 6 months; and Clarence R. Shoemaker, associate curator, on March 31, 1944, with over 33 years, 4 months of service. For disability, Eugene C. Miller, guard, on December 9, 1943, with 6 years, 1 month of service; Cecil R. Mulnix, guard, on March 31, 1944, with 13 years, 7 months service; Arthur G. Rodgers, guard, on November 10, 1943, with 8 years, 5 months service; Ann M. Stokes, laborer, on October 4, 1943, with 18 years, 6 months service; and Charles O. Watson, laborer, on April 5, 1944, with 35 years, 3 months service. By optional retirement, Royal H. Trembly, superintendent of buildings and labor, November 30, 1943, with over 49 years of service; Bertie Turner, attendant, on November 30, 1943, with 32 years, 6 months service; and Julian S. Warmbath, taxidermist, with 15 years of service.

Through death, the Museum lost during the year five employees from its active roll: Dr. Charles E. Resser, curator, division of in-

vertebrate paleontology and paleobotany, on September 18, 1943, after 29 years, 5 months; Miss Helen A. Olmsted, personnel officer, on January 11, 1944, after 43 years, 9 months; Benjamin F. Coe, guard, on March 1, 1944, after 25 years, 5 months; George E. Matheny, guard, on July 20, 1943, after 24 years, 6 months; and Cornelius S. Jones, laborer, on March 17, 1944, after 32 years, 6 months.

From its honorary staff, the Museum lost by death on September 5, 1943, Dr. Aleš Hrdlička, associate in anthropology since April 1, 1942; and on February 22, 1944, Dr. E. O. Ulrich, associate in paleontology since June 9, 1914.

Respectfully submitted.

ALEXANDER WETMORE, *Director.*

THE SECRETARY,
Smithsonian Institution.

APPENDIX 2

REPORT ON THE NATIONAL GALLERY OF ART

SIR: I have the honor to submit, on behalf of the Board of Trustees of the National Gallery of Art, the seventh annual report of the Board covering its operations for the fiscal year ended June 30, 1944. This report is made pursuant to the provisions of the Act of March 24, 1937 (50 Stat. 51), as amended by the public resolution of April 13, 1939 (Pub. Res. No. 9, 76th Cong.).

ORGANIZATION AND STAFF

During the fiscal year ended June 30, 1944, the Board was comprised of the Chief Justice of the United States, Harlan F. Stone; the Secretary of State, Cordell Hull; the Secretary of the Treasury, Henry Morgenthau, Jr.; and the Secretary of the Smithsonian Institution, Dr. C. G. Abbot, *ex officio*; and five general trustees, David K. E. Bruce, Ferdinand Lammot Belin, Duncan Phillips, Samuel H. Kress, and Chester Dale. Mr. Dale was elected as general trustee on November 1, 1943, to succeed Joseph E. Widener, who died on October 26, 1943.

At its annual meeting, held on February 14, 1944, the Board re-elected David K. E. Bruce, President, and Ferdinand Lammot Belin, Vice President, to serve for the ensuing year. The executive officers continuing in office during the year were:

Huntington Cairns, Secretary-Treasurer.

David E. Finley, Director.

Harry A. McBride, Administrator.

Huntington Cairns, General Counsel.

John Walker, Chief Curator.

Macgill James, Assistant Director.

Donald D. Shepard continued to serve during the year as Adviser to the Board.

During the year E. Roy Bergholz was appointed as Assistant Treasurer to succeed Charles Zinsner, who resigned; John A. Gilmore was appointed as Assistant General Counsel; Hanns Swarzenski was appointed Curator of Sculpture; and Porter A. McCray was appointed Chief of the Inter-American Office.

The Board of Trustees during the year was authorized and directed by the Foreign Funds Control of the United States Treasury Department, and at the request of the State Department, to assume custodian-

ship of all works of art and exhibition material sent to the United States under the auspices of the former French Government for exhibition purposes at various places in the United States, including the World's Fairs at New York, N. Y., and San Francisco, Calif.

On August 20, 1943, The American Commission for the Protection and Salvage of Artistic and Historic Monuments in War Areas was organized, and several executive officers of the Gallery were appointed to serve as officers of the Commission. The headquarters of the Commission are located in the Gallery building.

In March 1944 the Gallery, at the request of the State Department, established the Inter-American Office. This office was created to act as the official Government clearinghouse for the exchange of information concerning art activities in the American Republics.

The three standing committees of the Board, provided for in the bylaws, as constituted at the annual meeting of the Board, held February 14, 1944, were:

EXECUTIVE COMMITTEE

Chief Justice of the United States, Harlan F. Stone, chairman.
David K. E. Bruce, vice chairman.
Secretary of the Smithsonian Institution, Dr. C. G. Abbot.
Ferdinand Lamot Bello.
Duncan Phillips.

FINANCE COMMITTEE

Secretary of the Treasury, Henry Morgenthau, Jr., chairman.
David K. E. Bruce, vice chairman.
Secretary of State, Cordell Hull.
Ferdinand Lamot Bello.
Samuel H. Kress.

ACQUISITIONS COMMITTEE

David K. E. Bruce, chairman.
Ferdinand Lamot Bello, vice chairman.
Duncan Phillips.
Chester Dale.
David E. Finley, ex officio.

The permanent Government positions of the Gallery are filled from the registers of the United States Civil Service Commission or with its approval. On June 30, 1944, the permanent Government staff numbered 243 employees. Since the beginning of the war, 58 members of the staff, or approximately 25 percent, have entered the armed services.

The operation and maintenance of the Gallery building and grounds and the protection of the works of art have been continued through the fiscal year 1944 at as high a standard as possible with the reduced staffs now available. These staffs have been cut to a minimum owing to the fact that the Gallery has desired to reduce expenditures and

the use of manpower to the greatest possible extent during the war period. That it has been possible to maintain a fairly high standard is due solely to the intensive efforts, efficiency, and interest of the maintenance staff and the guard force. However, it will be necessary to increase both the maintenance staff and the guard force as soon as possible in order adequately to operate and maintain the Gallery building and grounds and to enable the Trustees to carry out their duties in the protection and care of the works of art in the Gallery's collections.

APPROPRIATIONS

For salaries and expenses for the upkeep and operation of the National Gallery of Art, the protection and care of works of art acquired by the Board, and all administrative expenses incident thereto as authorized by the Act of March 24, 1937 (50 Stat. 51), and amended by public resolution of April 13, 1939 (Pub. Res. No. 9, 76th Cong.), the Congress appropriated for the fiscal year ending June 30, 1944, the sum of \$623,365.00. This amount includes the present appropriation of \$541,365.00 and a supplementary deficiency appropriation amounting to \$82,000.00 for the payment of "overtime compensation" as authorized by Public Law 49, 78th Congress. From these appropriations the following expenditures and encumbrances were incurred:

EXPENDITURES AND ENCUMBRANCES

Personal services.....	\$510, 665. 00
Printing and binding.....	4, 047. 22
Supplies and equipment, etc.....	103, 315. 03
Unencumbered balance.....	5, 337. 75
<hr/>	
Total.....	623, 365. 00

In addition to the above-mentioned appropriations, the Gallery received \$15,932.16 from the Federal Works Agency, Public Buildings Administration, to cover expenses incurred in connection with the special protection of paintings and sculpture evacuated from the Gallery.

ATTENDANCE

During the fiscal year ended June 30, 1944, the visitors to the National Gallery of Art totaled 2,060,071, the largest annual attendance since the opening of the Gallery. This compares with 1,508,081 during the fiscal year ended June 30, 1943, or an increase of 551,990 or 36.6 percent. The increase in popularity of the Gallery is evidenced by the fact that the average daily attendance during the fiscal year 1944 was 5,659 visitors, as compared with 4,143 for the fiscal year 1943. On Sunday, December 21, 1943, there were 22,248 visitors, the greatest number in any one day.

Contributing to the public's increasing interest in the Gallery are the evening hours on Sunday, the special exhibitions, particularly those of wartime art, the Sunday evening concerts without charge, and the Servicemen's Room, which provides a place of relaxation for men and women in the armed services. Approximately 30 percent of the visitors to the Gallery are men and women in the armed services.

PUBLICATIONS

The Information Rooms in the Gallery continue to offer an increasing variety of fine, although moderately priced, colored reproductions of paintings in the Gallery's collections, as well as post cards, illustrated catalogs, and a general information booklet that is of great assistance to visitors and which may be obtained without charge. With the acquisition of the Lessing J. Rosenwald collection of prints and drawings, a large illustrated catalog of this collection and a set of 32 post-card reproductions of some of the prints and drawings in the collection have been added to the publications now available.

During the past year there has been a great increase in the number of orders for the Gallery's publications from servicemen overseas, who are purchasing color prints and catalogs for use in recreation rooms at military posts all over the world. There has also been an unusual demand from public schools throughout the United States for color reproductions and text material descriptive of the Gallery's collections. These publications also are in demand in the Latin-American republics.

WORKS OF ART STORED IN PLACE OF SAFEKEEPING

Early in January 1942 a limited number of fragile and irreplaceable works of art in the Gallery's collections were removed to a place of greater safety. These works, stored in a place adapted for the purpose, have since been under constant guard by members of the Gallery's guard force and under supervision and inspection by a member of the curatorial staff of the Gallery.

ACQUISITIONS

GIFTS OF PRINTS AND DRAWINGS

The Board of Trustees, on December 4, 1943, accepted six etchings from David Keppel, five by Piranesi and one by Ugo de Carpi. Also on December 4 the Board accepted a gift of two drawings, "Seated Figure," by Pascin, and "Head of a Girl," by Puvis de Chavannes, from Lessing J. Rosenwald. On May 20, 1944, the Board accepted an additional gift of approximately 196 prints and drawings from Mr.

Rosenwald. The Index of American Design, consisting of 22,000 or more drawings and water colors, which was accepted by the Board on June 7, 1943, from the Works Progress Administration, was received in the Gallery during the fiscal year 1944.

GIFTS OF PAINTINGS

On December 4, 1943, the Board of Trustees accepted eight paintings from Lessing J. Rosenwald, viz:

<i>Title</i>	<i>Artist</i>
The Stockade.....	Forain.
The Petitioner.....	Forain.
Artist and Model.....	Forain.
Behind the Scenes.....	Forain.
Feast of the Gods.....	Daumier.
In Church.....	Daumier.
Peach Blossom.....	Whistler.
Arnold Hannay.....	Whistler.

On the same date it also accepted the painting entitled "Breezing Up," by Winslow Homer, from the W. L. and May T. Mellon Foundation. On December 18, 1943, the Board accepted the portrait of "Commodore John Rodgers," by John Wesley Jarvis, from the Misses Christina and Nannie R. Macomb. On February 14, 1944, the Board accepted two paintings, "The Stream," by Courbet, and "The Eel Gatherers," by Corot, from Mr. and Mrs. P. H. B. Frelinghuysen. From the children of the late Rt. Rev. William Lawrence, the Board on the same date accepted the painting entitled "Amos Lawrence," by Chester Harding; and on May 20, 1944, the Board accepted the painting of "Horace Binney," by Gilbert Stuart, as a gift from Dr. Horace Binney.

SALE OR EXCHANGE OF WORKS OF ART

During the year no works of art belonging to the Gallery were sold or exchanged.

LOAN OF WORKS OF ART TO THE GALLERY

During the year the following works of art were received on loan: From Mrs. John C. Clark of New York, N. Y.:

60 etchings by Pennell.

From Mrs. Cary Grant, Pacific Palisades, Calif.:

<i>Title</i>	<i>Artist</i>
A Fete Day, Venice.....	Canaletto.
The Courtyard, Doge's Palace, with the Procession of the Papal Legate.....	Canaletto.

LOAN OF WORKS OF ART BY THE GALLERY

In the fiscal year ended June 30, 1944, the Gallery loaned the following five paintings to the Lyman Allyn Museum, New London, Conn., for exhibition purposes:

From the collection of the National Gallery of Art:

<i>Title</i>	<i>Artist</i>
Self Portrait.....	Benjamin West.
Major Thomas Biddle.....	Thomas Sully and Thomas Wilcocks Sully.

From the loan collection of The A. W. Mellon Educational and Charitable Trust:

<i>Title</i>	<i>Artist</i>
Anna Cora Mowatt (?).....	attributed to John James Audubon.
Gilbert Stuart's Family (?).....	attributed to Washington Allston.
Peter R. Livingston (?).....	attributed to Abraham Delanoy.

LOANED WORKS OF ART RETURNED

During the year the following works of art lent to the Gallery by Chester Dale of New York, N. Y., were returned to him:

<i>Title</i>	<i>Artist</i>
Crouching Lion.....	Delacroix.
Nude Woman Seated on a Bed.....	Forain.
Woman Seated on a Chair.....	Forain.
Monsieur Louis Roy.....	Gauguin.
Cottage Interior with Woman and Little Girl.....	Millet.

EXHIBITIONS

The following exhibitions were held at the National Gallery of Art during the fiscal year ended June 30, 1944:

Group of political caricatures by French and British artists, from the Lessing J. Rosenwald collection, from July 31 to September 5, 1943.

Nineteenth- and twentieth-century drawings and water colors from French museums and private collections (2d showing) from August 8 to September 5, 1943.

"Art for Bonds," by American artists and sponsored by the Treasury Department's National Committee of Honorary Patrons, in connection with the Treasury's Third War Loan Campaign, from September 12 to October 10, 1943.

Marine water colors and drawings by officers and enlisted men of the U. S. Marine Corps, through cooperation of the Division of Public Relations, U. S. Marine Corps, from September 12 to October 10, 1943.

Navaho pollen and sand paintings. Selections from a group of paintings executed by Miss Maud Oakes, and accompanied by a group

collected by Miss Mary Wheelwright, from October 17 to November 14, 1943.

Paintings of naval aviation by American artists. From the Abbott Laboratories and in cooperation with the U. S. Navy, from November 21 to December 12, 1943.

Prints and drawings from the Rosenwald collection. The first general exhibition of prints and drawings from the Lessing J. Rosenwald collection, comprising a group of selections from the fifteenth century to the present time, from December 19, 1943, to February 13, 1944.

Etchings and lithographs by Goya from the Gallery's collection, from January 23 to February 13, 1944.

"The Army at War," paintings and drawings by American artists at Army bases throughout the world. Exhibition lent by the War Department to the Treasury Department, and shown at the National Gallery of Art from February 20 to March 19, 1944.

Index of American Design. First exhibition of a selection of drawings and water colors (from the Metal Work and Hooked Rug sections), from March 26 to April 23, 1944.

Nanteuil engraved portraits. A selection of 35 of Nanteuil's works, from the Lessing J. Rosenwald collection, from March 26 to June 21, 1944.

British war paintings. An exhibition of official British war paintings, recording military operations and civilian activities in wartime Britain. Lent by the British Ministry of Information, from April 23 to May 20, 1944.

Rembrandt prints and drawings. A survey of the work of the great Dutch master, selected from the Rosenwald, Widener, Rice, and Nowell-Usticke collections, from April 30 to June 21, 1944.

TRAVELING EXHIBITIONS

During the fiscal year ended June 30, 1944, the following drawings, water colors, and prints were placed on exhibition:

INDEX OF AMERICAN DESIGN

Exhibition made up from the documented drawings and water colors contained in the Index of American Design. Six drawings, together with data sheets, for use in an Exhibition of Maine Art, opening April 14, 1944, were shipped to Colby College, Waterville, Me., and were returned to the Gallery June 15, 1944.

Ninety-five duplicate data sheets of Texas material contained in the Index, from which to make a selection of photographs, were shipped to the University of Texas, Austin, Tex., on June 27, 1944.

ROSENWALD PRINTS

A traveling exhibition, consisting of 35 prints from the Lessing J. Rosenwald collection. Sent on May 6, 1944, to Brooks Memorial Art Gallery, Memphis,

Tenn.; then to the Virginia Museum of Fine Arts, Richmond, Va., on June 12, 1944, from where it will be returned to the National Gallery of Art about August 1, to be held for further bookings.

VARIOUS GALLERY ACTIVITIES

In the period from July 1, 1943, to June 30, 1944, a total of 53 concerts were given, of which 52 were in the East Garden Court on Sunday evenings and one on Saturday afternoon in the Auditorium. The concerts were free to the public, and were attended to capacity. The National Gallery Sinfonietta, under the direction of Richard Bales, played 13 concerts. An American Festival of works of native composers was held during March and April, 1944, when five performances were given.

The Sunday night suppers for servicemen have been continued during the year, approximately 35 being served each Sunday in the cafeteria at the Gallery. Funds to defray the cost of the suppers were contributed by members of the staff and by friends of the Gallery.

A total of 195 special permits to copy paintings in the National Gallery of Art were issued during the fiscal year 1944, and 72 special permits were issued during the same period to photograph paintings.

CURATORIAL DEPARTMENT

During the year the work of the curatorial department consisted mainly of installing a large number of gifts and additional works of art from the Widener collection; arranging 17 temporary exhibitions; cataloging paintings, sculpture, and prints; assisting the American Commission for the Protection and Salvage of Artistic and Historic Monuments in War Areas by providing information on damaged and looted works of art in war areas; and the assumption of additional responsibility resulting from the appointment of the Trustees of the Gallery as custodian of works of art and exhibition material sent to this country under the auspices of the former French Government.

Two publications, "Great American Paintings from Smibert to Bellows," edited by John Walker and Macgill James, and "Masterpieces of Painting from the National Gallery of Art," edited by Huntington Cairns and John Walker, were prepared with the assistance of members of the curatorial department. One book, two catalogs, and three pamphlets were issued by the curatorial and educational departments in collaboration. Six members of the staff contributed eight articles to several periodicals and pamphlet series.

During the past year approximately 622 works of art were submitted to the acquisitions committee (the largest individual gift being 490 prints and drawings to be added to the Rosenwald collection) with recommendations regarding their acceptability for the collections of

the National Gallery of Art; 45 private collections were viewed in connection with offers to the Gallery of gifts or loans; 94 consultations were held concerning 139 works of art brought to the Gallery for expert opinion; and 58 written replies were made to inquiries involving research in the history of art.

RESTORATION AND REPAIR OF WORKS OF ART

With the authorization of the Board, and the approval of the Director and Chief Curator, the necessary restoration and repair of paintings and sculpture in the Gallery's collection were made by Stephen S. Pichetto, Consultant Restorer to the Gallery. All the work was completed in the Restorer's studio in the Gallery with the exception of several paintings that required restoration before shipment to Washington, and one where the work was of such a delicate and complicated nature that it was necessary for the work to be done in Mr. Pichetto's New York studio.

EDUCATIONAL PROGRAM

More than 72,000 people attended the various programs conducted by the educational department during the year. The Gallery tours of the collection attracted nearly 15,000 people, while 22,000 attended the "Picture of the Week," a 10-minute discussion of a single painting given twice daily on Mondays through Fridays. More than 9,000 attended the regular lectures on special topics delivered by the educational staff and guest speakers.

During the first 4 months of the fiscal year, a new project undertaken by the educational department was that of an automatic program (no speaker) employing 2 x 2 Kodachromes and titles on slides, entitled "What To See in the National Gallery of Art—A Suggestion for Your First Visit." This program was accompanied by recorded music, and more than 15,000 people attended.

LIBRARY

The most important contribution to the library during the year was the art library of the late Joseph E. Widener. This gift consisted of 1,373 books and 579 periodicals.

As a gift from Solomon R. Guggenheim, the library received the Richter Archives, consisting of over 60,000 photographs and reproductions. Mr. Guggenheim also gave 975 photographs of art objects in the Solomon R. Guggenheim collection. A number of books on works of art were also added to the library collection through funds donated by Capt. Paul Mellon.

PHOTOGRAPHIC DEPARTMENT

During the fiscal year 1944, the photographic laboratory of the Gallery made 6,037 black-and-white prints and 510 black-and-white and 1,117 color slides.

OTHER GIFTS

In the fiscal year ended June 30, 1944, gifts of books on works of art and related material were made to the Gallery library by the Honorable Solomon Bloom, Mrs. Juliana Force, Mrs. Victor Harris, Macgill James, Pvt. Lincoln Kirstein, Leander McCormick-Goodhart, Capt. Paul Mellon, Lamont Moore, John H. Morgan, W. Francklyn Paris, Duncan Phillips, and Maj. Ray L. Trautman. Gifts of money were made to the Gallery during the year by Mrs. Florence Becker, David E. Finley, Mrs. Deering Howe, Mr. and Mrs. Macgill James, Life Magazine, Mrs. H. A. McBride, Capt. Paul Mellon, Donald D. Shepard, Col. and Mrs. O. J. Troster, and the late Joseph E. Widener.

AUDIT OF PRIVATE FUNDS OF THE GALLERY

An audit is being made of the private funds of the Gallery for the year ended June 30, 1944, by Price, Waterhouse & Company, public accountants, and the certificate of that company on its examination of the accounting records maintained for such funds will be submitted to the Gallery.

Respectfully submitted.

F. L. BELIN, *Acting President.*

THE SECRETARY,
Smithsonian Institution.

APPENDIX 3

REPORT ON THE NATIONAL COLLECTION OF FINE ARTS

SIR: I have the honor to submit the following report on the activities of the National Collection of Fine Arts for the fiscal year ended June 30, 1944:

APPROPRIATIONS

For the administration of the National Collection of Fine Arts by the Smithsonian Institution, including compensation of necessary employees, purchase of books of reference and periodicals, traveling expenses, and other necessary incidental expenses, \$17,486 was allotted, of which \$6,364.74 was expended in connection with the care and maintenance of the Freer Gallery of Art, a unit of the National Collection of Fine Arts. The balance was spent for the care and upkeep of the National Collection of Fine Arts, nearly all of this sum being required for the payment of salaries, traveling expenses, purchase of books and periodicals, and necessary disbursements for the care of the collection.

THE SMITHSONIAN ART COMMISSION

Owing to crowded transportation conditions and lack of proper hotel facilities, it was decided to omit again the December annual meeting of the Smithsonian Art Commission. Several proffered gifts of art works have been deposited with the National Collection of Fine Arts to be passed upon at the next meeting of the Commission.

The Commission lost one member by death during the year. Dr. Frederick P. Keppel, a member of the Commission since 1932, died September 8, 1943.

THE CATHERINE WALDEN MYER FUND

Four miniatures, water color on ivory, were acquired from the fund established through the bequest of the late Catherine Walden Myer, as follows:

42. "Charles Carroll," by Henry Inman (1801-1840); from Mrs. Dora Lee Curtis, Arlington, Va.

43. "William E. Dickson," by Rembrandt Peale (1778-1800); from Mrs. J. J. Hooper, Washington, D. C.

44. "Katherine Douglas Dickson," by Raphael Peale (1774-1825); from Mrs. J. J. Hooper, Washington, D. C.

45. "British Officer," by Alfred T. Agate (1812-1846); from Miss Elizabeth A. DuHamel, Washington, D. C.

LOANS ACCEPTED

A miniature, "Otto, Count de Mosloy," by Charles Willson Peale, 1779, was lent by Dr. L. P. Shippen on September 24, 1943.

An oil painting, "Portrait of Mrs. Stephen Decatur, nee Susan Wheeler (1776-1860)," by Gilbert Stuart (1755-1828), and four crayon drawings on paper, "Portrait of Ann Decatur Pine," "Portrait of Capt. James McKnight," "Portrait of Capt. Stephen Decatur, Sr.," and "Portrait of Ann Pine McKnight Decatur," by Saint-Memin (1770-1852), were lent by Mrs. William F. Machold, nee Sarah Morris, on November 22, 1943.

Thirty Chinese jade ornaments were lent anonymously on March 1, 1944.

A miniature, "Col. Nathaniel Darby," by an unknown artist, was lent by Dr. L. P. Shippen on March 25, 1944.

Two miniatures, "John Church Hamilton," and "Unknown Lady," by Alfred T. Agate (1812-1846), were lent by Miss Elizabeth A. DuHamel on April 7, 1944.

A miniature, "William Parsons, 2nd, of Gloucester, Mass.," by Washington Blanchard (ac. 1831-43, Boston), was lent by Mrs. Alba Walling on May 18, 1944.

An oil painting, "Portrait of Lt. Gen. Mark W. Clark," by M. Arnold Nash, was lent by Mrs. Mark W. Clark on June 7, 1944.

LOANS TO OTHER MUSEUMS AND ORGANIZATIONS

The following 13 paintings were lent to the Civilian Medical Division, Office of the Secretary of War, Dr. F. C. Smith, Medical Director, Room 1 E 356, Pentagon Building, on July 21, 1943, with the understanding that they can be recalled at any time.

"Street Scene in Ajmere," by William S. Bagdatopoulos.

"Peshawar City from the Fort," by William S. Bagdatopoulos.

"Peachbloom," by Alice Pike Barney.

"Landscape with Pond," by John L. Bennett.

"The Woodland Way," by William Baxter Closson.

"Joyous Childhood," by William Baxter Closson.

"Near the Ocean," by Robert Swain Gifford.

"On the Lagoon, Venice," by Robert Swain Gifford.

"Landscape with Windmill," by E. Landseer Harris.

"Great Silas at Night," by Robert C. Minor.

"The Brook," by Clinton Ogilvie.

"The Patriarchs, Zion National Park," by Gunnar Widforss.

"The Artist's Children," by John Wood.

A marble statue, "Greek Slave," by Hiram Powers (without the pedestal), was lent to the Metropolitan Museum of Art, New York City, for an exhibition "The Greek Revival in the United States," November 8, 1943, to March 1, 1944. (Returned March 7, 1944.)

Two oil paintings, "Cliffs of the Upper Colorado River, Wymoing Territory," by Thomas Moran, and "Fired On," by Frederic Remington, were lent to The Museum of Modern Art, New York City, for an exhibition of "Romantic Painting in America," November 17 through February 6, 1944. (Returned February 18, 1944.)

An oil painting, "Thomas A. Edison Listening to his First Perfected Phonograph," by Col. A. A. Anderson, was lent to the Department of Engineering and Industries, United States National Museum, on February 11, 1944, to be used in connection with a special exhibition commemorating the ninety-seventh birthday of Edison. (Returned March 3, 1944.)

The following five miniatures were lent to the Lyman Allyn Museum, New London, Conn., to be included in the exhibition of John Trumbull and his contemporaries from March 5 to April 16, 1944. (Returned April 19, 1944.)

"Mr. Nichol," by John Wesley Jarvis.

"Elizabeth Oliphant," by James Peale.

"Elizabeth Knapp," by James Peale.

"Robert Oliphant," by Raphael Peale.

"Rubens Peale," by Raphael Peale.

An oil painting, "Portrait of Frank B. Noyes," by Ossip Perelma, was lent to the artist to be shown in connection with his exhibition of portraits held at the Mayflower Hotel, Washington, D. C., May 9 to June 1, 1944. (Returned June 5, 1944.)

WITHDRAWALS BY OWNERS

The following six paintings, lent by the Rev. F. Ward Denys, were withdrawn November 3, 1943, by the executor of his estate, the American Security and Trust Company.

"The Salutation," copy after Albertinelli.

"Holy Family," copy after Del Sarto.

"Gathering Flowers," by E. Keyser.

"St. Michael and the Dragon," copy after Guido Reni.

"Madonna and Child," copy after Perugino.

"St. Anthony and the Lions," by unknown artist.

The bronze statue of Lincoln, by Augustus Saint-Gaudens, lent by the estate of Mrs. John Hay, was withdrawn December 13, 1943.

An oil painting, "Portrait of a Dutch Girl," by Jan Victoors, was withdrawn December 31, 1943, by Mrs. Feroline Perkins Wallach, Administratrix of the Estate of Cleveland Perkins.

Two oil paintings, "The Windmill," by Salomon Ruysdael, and "Portrait of a Dutch Girl," by Paul Moreelse, were withdrawn May 15, 1944, by Mrs. Feroline Perkins Wallach, Administratrix of the Estate of Cleveland Perkins.

THE HENRY WARD RANGER FUND PURCHASES

No. 113 entitled "Fifteenth Century French Madonna and Child," by Harry W. Watrous (1857-1940), was assigned by the Council of the National Academy of Design to the Coker College for Women, Hartsville, S. C., on August 4, 1943.

THE NATIONAL COLLECTION OF FINE ARTS REFERENCE LIBRARY

A total of 651 publications (329 volumes and 322 pamphlets) were accessioned during the year. This number includes 171 volumes and 52 pamphlets added by purchase, and 60 volumes of bound periodicals. The Parke-Bernet priced catalogs accounted for 31 volumes and 45 pamphlets among the purchases. The other accessions were publications received in exchange or as gifts.

OTHER ACTIVITIES

The following paintings have been cleaned or restored since July 1, 1943:

"Portrait of Andrew Jackson," by Thomas Sully. Property of the United States Capitol.

"Portrait of Commodore Oliver H. Perry," by John Wesley Jarvis (or after). Property of the division of history, United States National Museum.

"City of St. Louis," by George Catlin. Property of the division of ethnology, United States National Museum.

"Ha-won-je-tah, the One Horn. Sioux (Dah-Co-Ta)," by George Catlin. Property of the division of ethnology, United States National Museum.

"View on Upper Missouri—Back View of the Mandan Village," by George Catlin. Property of the division of ethnology, United States National Museum.

"Buffalo Hunt under the Wolf-skin Mask," by George Catlin. Property of the division of ethnology, United States National Museum.

"Portrait of Robert Morris," by Gilbert Stuart (or after), offered to the National Collection of Fine Arts by the Medical Society of the District of Columbia.

SPECIAL EXHIBITIONS

The following exhibitions were held:

October 6 through 31, 1943.—Exhibition of 13 oil and 2 varnish paintings, 4 water colors, 1 gouache, 4 pencil drawings and 2 etchings, by Ceferino Palencia, of Mexico, was sponsored by the Mexican Ambassador and the Pan American Union. A catalog was published by the Pan American Union.

December 3, 1943, through January 2, 1944.—Exhibition of 74 water colors of Mexico, by Walter B. Swan, Omaha, Nebr., was sponsored by the Mexican Ambassador and the Pan American Union. A catalog was published by the Pan American Union.

December 14, 1943, through January 16, 1944.—Exhibition of 82 miniatures by 52 artists, by the Pennsylvania Society of Miniature Painters. Reprint of catalog was published by the National Collection of Fine Arts.

January 6 through 30, 1944.—Exhibition of 21 water colors and 20 block prints, by Ralph H. Avery, C. Sp. (P.), United States Navy.

February 4 through 27, 1944.—Joint exhibition of paintings by John Mix Stanley (1814-72), his daughter-in-law, Jane C. Stanley (1863-1940), and her daughter, Alice Stanley Acheson, consisting of 30 oil paintings, 3 chromolithographs, and 7 small lithographs by John Mix Stanley, a photograph of John Mix Stanley, and a book entitled "John Mix Stanley and his Indian Paintings," by W. Vernon Kinitz; 40 water colors by Jane C. Stanley, and 28 oils by Alice Stanley Acheson. A catalog was privately published.

April 29 through May 2, 1944.—Biennial Art Exhibition of 20 water colors, 41 oils, 4 etchings, 2 pastels and 4 pieces of sculpture, by the National League of American Pen Women. A catalog was privately published.

May 2 through 28, 1944.—Exhibition of "Portraits of Leading American Negro Citizens," 8 by Mrs. Laura Wheeler Waring, of Philadelphia, Pa., and 15 by Mrs. Betsy Graves Reyneau, of Washington, D. C.

June 2 through 28, 1944.—Exhibition of 78 mural paintings from the caves of India, and 16 paintings of modern India, by Sarkis Katchadourian, of New York City. A catalog was published by the State Department.

PUBLICATIONS

TOLMAN, R. P. Report on the National Collection of Fine Arts for the year ended June 30, 1943. Appendix 3, Report of the Secretary of the Smithsonian Institution for the year ended June 30, 1943, pp. 35-40.

WENLEY, A. G. Report on the Freer Gallery of Art for the year ended June 30, 1943. Appendix 4, Report of the Secretary of the Smithsonian Institution for the year ended June 30, 1943, pp. 41-46.

Respectfully submitted.

R. P. TOLMAN, *Acting Director.*

THE SECRETARY,
Smithsonian Institution.

APPENDIX 4

REPORT ON THE FREER GALLERY OF ART

Sir: I have the honor to submit the twenty-fourth annual report on the Freer Gallery of Art for the year ended June 30, 1944:

THE COLLECTIONS

Additions to the collections by purchase are as follows:

BRONZE

- 43.9. Chinese, 12th century B. C. Shang dynasty. Ceremonial vessel of the type *ku*. Light green patina with patches of silvery gray inside and out; incrustations of cuprite and native copper inside and out. Surface design incised and filled with a reddish pigment. A two-character inscription inside the foot. 0.203 x 0.167 over all.
- 44.1. Chinese, 12th century B. C. Shang dynasty. A ceremonial vessel of the type *tsun*. Light green patina; incrustations of cuprite and azurite inside. Traces of red and black pigments in the design. A three-character inscription with *ya hsing* inside on the bottom. 0.297 x 0.231 over all. (Illustrated.)
- 44.3. Chinese, Han dynasty (206 B. C.-A. D. 221). Mirror. Surface: a black patina with overlay of green aerugo on the face and on the rim of the back. Decoration in low relief with four characters around the boss. Diameter: 0.142.
- 44.4. Chinese, T'ang dynasty (A. D. 618-907). Mirror. Surface: a bright silvery patina with patches of green aerugo. Decoration of birds, animals, insects, and flowers in relief. Diameter: 0.192.
- 44.5. Chinese, T'ang dynasty (A. D. 618-907). Mirror. Surface: a silvery patina with occasional patches of green aerugo. Decoration of grapes, birds, and animals, in bold relief. Diameter: 0.212.
- 44.6. Chinese, early Han, 3d century B. C. Mirror. Surface: a tarnished silvery patina with patches of green aerugo. Decoration: fine incised background with designs in flat relief superimposed. Diameter: 0.100.
- 44.7. Chinese, Sui dynasty (A. D. 581-618). Mirror. Surface: a bright silvery patina with remains of green lacquer spilled over the edge; boss incrustated with green aerugo. Decoration in relief with additions of red and green pigment. Inscription of 27 characters. Diameter: 0.184.
- 44.8. Chinese, T'ang dynasty (A. D. 618-907). Mirror. Surface: a tarnished silvery patina covered with patches of green aerugo. Decoration: lacquer inlaid with silver and gold. 0.150 x 0.159.
- 44.9. Chinese, 3d-2d century B. C. Mirror. Surface: a black patina with patches of green aerugo. Decoration: background incised, with a smooth circular band and a seven-pointed star superimposed in countersunk relief. Diameter: 0.190.
- 44.10. Chinese, 3d-2d century B. C. Mirror. Surface: a black patina with patches of green aerugo. Decoration in low linear relief. Diameter: 0.142.



44.1



44.14



44.17



44.20

RECENT ADDITIONS TO THE COLLECTION OF THE FREER GALLERY OF ART.

CERAMICS

- 44.11. Chinese, Sung dynasty. *Ko* ware. Dish with sloping sides and six-foil rim. Body of hard, dark gray clay showing brown on the foot-rim, covered with an opaque, buff-gray glaze with a medium crackle and some small iron spots. 0.031×0.132 .
- 44.12. Chinese, Sung dynasty. *Yüeh* ware. Round, covered box with a design of three flowers carved in low relief on the top. Body of hard, fine-grained medium-gray clay, covered with a transparent, greenish-gray glaze which shows green in thicker areas. 0.052×0.137 .
- 44.13- Chinese, Ch'ing dynasty, Ch'ien Lung period. Pair of bowls, each with a stem attached into a free-moving reticulated base. The body of each is of white porcelain, covered with a pure white glaze upon which the decoration is painted in overglaze enamels. The base of each is glazed in celadon. On the foot of each stem a six-character mark of the Ch'ien Lung period in underglaze blue. 44.13, 0.131×0.164 over all; 44.14, 0.135×0.163 over all. (44.14 illustrated.)
- 44.15. Chinese, Sung dynasty. *Ting* ware. Small plate, with a slight concavity and a narrow rim, bound in brass. The body is of white porcelainous clay, covered with a lustrous, cream-white glaze. The decoration of ducks, lotuses, and water plants in slight relief under glaze. 0.017×0.140 (diameter).

JADE

- 44.18. Chinese, 18th century. Ch'ien Lung period (1736-95). A tripod vessel of a-b-c. the *ting* type with a cover surmounted by a lion *sejant*; annular handles depending from dragon heads in relief; all carved from a single piece of white nephrite. Wood stand. 0.250×0.283 over all.

LACQUER

- 44.19. Japanese, late 17th century. Writing box (*suzuri-bako*) in polished black lacquer (*rō-iro*) decorated in gold and pewter. Bronze water box (*mizu-iro*) and an ink stone; two trays. $0.051 \times 0.226 \times 0.221$.
- 44.20. Japanese, 14th century. Late Kamakura. Small cabinet (*kodansu*) in polished black lacquer (*rō-iro*) now turning brown. Decorations of chrysanthemums, grasses, butterflies, and vines executed in gold and mother-of-pearl. Six drawers and two doors; lock, hinges, etc., in dark, chiseled bronze. $0.280 \times 0.334 \times 0.213$. (Illustrated).
- 44.21. Japanese, 16th century. Painter's box (*e-bako*) in two parts with cover and tray in upper part. Polished black lacquer (*rō-iro*) inlaid with closely set small chrysanthemums of mother-of-pearl, whose surfaces are engraved with the lines of the petals. $0.203 \times 0.172 \times 0.338$.
- 44.23. Japanese, late 17th century. Letter-box (*fu-bako*) with gold-flecked ground (*nashiji*) upon which the decoration is executed in varying tones of gold and silver. Silver fittings. $0.075 \times 0.250 \times 0.096$.
- 44.26. Japanese, dated in correspondence with A. D. 1844. By Yamamoto Shunshō. Medicine chest (*yakurō*), Polished black lacquer (*rō-iro*) containing six drawers; silver corner mountings. Decorations executed in black lacquer in relief, and in gold and red. Inscription of 11 characters including date, signature, and *kakihan*. One seal. $0.338 \times 0.328 \times 0.193$.
- 44.22. Japanese, 17th-19th century. Three writing boxes (*suzuri-bako*).
- 44.24.
- 44.25.

- 44.27- Japanese, 17th-18th century. Eighteen medicine cases (*inro*) of varying
 44.44 types and designs.
 incl.

MANUSCRIPT

- 44.17. Armenian, 13th century. *The Gospel* according to the four Evangelists. Original binding of tooled brown leather, the top cover adorned with a cruciform design executed in silver nailheads; at its center a square crystal containing a Greek cross cut into it from underneath; other small silver appliques (some missing). The text is written on 582 parchment leaves in double columns, in *bolorgir* or "round hand," in black, gold, and occasional blue, red, and green. Initials, paragraphs, title pages, arcades, and four full-page miniatures with figures of the Evangelists—executed in colors and gold. Dated colophons. 0.244 x 0.179 over all. 0.240 x 0.169 average page. (Page 28 illustrated.)

PAINTING

- 43.10. Chinese, dated in correspondence with A. D. 1541. Ming dynasty. By Wen Pi (Ch'eng-ming), 1470-1559. Chrysanthemums and pine tree. Ink painting on a paper scroll. Dated and signed by the artist; two colophons, one by the artist; 20 seals. 0.755 x 0.315.
 44.16. Chinese, dated in correspondence with A. D. 1684. Ch'ing dynasty. By Tao-chi (fl. circa A. D. 1662-1706). Landscape. Ink and slight color on a paper scroll. Inscription, signature, and four seals on the painting; inscription and three seals on the mount. 0.264 x 3.132.
 44.45. Japanese, dated in correspondence with A. D. 1773. Attributed to Ōkyo. Pilgrims going to Hase-dera in the springtime. Color and ink on a silk kakemono. Inscription, signature, two seals. 0.447 x 0.812.

STONE SCULPTURE

- 44.2. Chinese, 8th century. T'ang dynasty. Head belonging to the dancing figure in the processional relief 24.2 (reattached). 0.115 x 0.068 x 0.068.

The work of the curatorial staff has been devoted to the study of new acquisitions and of other objects submitted for purchase, from the fields of Chinese, Japanese, Arabic, Persian, and Indian fine arts. Such work involves comparative study, reading of inscriptions and seals, written reports, and so on. In addition to the work within the collection, reports, either oral or written, were made upon 658 objects and 122 photographs of objects submitted for examination by their owners, and 44 inscriptions were translated. A large part of the time of staff members has been given to work directly contributing to the war effort, summarized as follows:

WAR WORK

Members of the staff devoted many hours both inside and outside regular hours to work for several Government agencies. Five hundred forty-two typed pages of Japanese translations were made for the Office of Strategic Services; and a revised translation of a

Guide to Signs and Symbols used on Chinese military maps were made and a compilation of a glossary of Chinese geographical and topographical terms was edited and revised for the Army Map Service. The Chinese character for "Victory" was made for an artist to be used in connection with a publication on the United Nations. Photographs made by the Freer Gallery field staff in China were reproduced for the Military Intelligence Division of the War Department (27 prints). For another agency, several Japanese documents were examined.

Other services have been given to various persons. For example, 63 photographs of Chinese paintings were presented to Dr. Shih-chieh Wang, Secretary General of the People's Council and Central Planning Board of China and a member of the Chinese Goodwill Mission; 557 photographs were given to members of the armed services who visited the offices; 24 military students of the School of Foreign Service, Georgetown University, were shown through the Chinese exhibition galleries; and in Santa Fe, N. Mex., a lecture on "Flower Painting in the Near and the Far East" was given by a staff member using Freer Gallery material, for the benefit of the Indian Service Club.

CHANGES IN EXHIBITION AND REPAIRS TO THE COLLECTION

Six hundred eighty-eight changes in exhibition have been made, as follows:

American paintings:

Oils, 79; water colors, 35; pastels, 22.

American prints (Whistler):

Etchings, 32; lithographs, 21.

Biblical manuscripts, 6.

Coptic book covers, 4.

Chinese arts:

Bronzes, 47; bronze and jade, 4.

Ceramics, 40.

Jade, 152.

Marble, 2.

Paintings, 117.

Silver, 36.

Sculpture, bronze, 32.

Sculpture, stone, 30.

Korean pottery, 27.

Syrian glass, 2.

Repairs to the collection were as follows:

One Chinese bronze repaired; 1 Persian painting remounted; 5 Japanese paintings remounted; 31 Chinese paintings bound in portfolio form.

Sculptured head 44.2 cemented upon its original place on the figure of the dancer of the Chinese Buddhist relief 24.2.

ATTENDANCE

The Gallery has been open to the public every day from 9 until 4:30 o'clock with the exception of Mondays and Christmas Day.

The total attendance of visitors coming in at the main entrance was 62,408. Fifty-four other visitors on Mondays bring the grand total to 62,462. The total attendance on weekdays was 35,610; Sundays, 26,798. The average weekday attendance was 137; the average Sunday attendance, 515. The highest monthly attendance was in August, with 6,789 visitors, the lowest in December with 3,394 visitors.

There were 1,279 visitors to the main office during the year; the purposes of their visits were as follows:

For general information.....	180
To see members of the staff.....	505
To read in the library.....	213
To make tracings and sketches from library books.....	5
To see building and installations.....	37
To make photographs and sketches.....	15
To see exhibition galleries on Monday.....	0
To examine or purchase photographs and slides.....	378
To submit objects for examination.....	96
To see objects in storage.....	209
<i>Washington Manuscripts</i>	56
Far Eastern paintings and textiles.....	36
Near Eastern paintings and manuscripts.....	26
Tibetan paintings.....	1
Indian paintings.....	1
American paintings.....	8
Oriental pottery, jade, bronze, lacquer and bamboo.....	72
Gold treasure.....	3
All sculpture.....	5
Syrian glass, etc.....	1

DOCENT SERVICE, LECTURES, ETC.

By request, 2 groups met in the study rooms and 13 groups in the exhibition galleries for instruction by staff members. Total number of persons, 321.

January 21, 1944: The Director attended a meeting in New York of the Committee of the American Council of Learned Societies on Protection of Cultural Treasures in War Areas.

February 10, 1944: A lecture by Miss Guest, on "Flower Painting in Persia and China," before the American Association of University Women.

Two lectures by members of the Civil Service Commission were given to supervisors in the auditorium. Total attendance, 224.

PERSONNEL

Weldon N. Rawley resigned from the Civil Service position of superintendent of building (CAF-8) August 15, 1943. He was appointed by the Freer Gallery as superintendent of building, court and grounds, August 16, 1943.

Rita W. Edwards resigned from the Civil Service position of senior clerk-stenographer (CAF-5) October 8, 1943. She was appointed by the Freer Gallery as administrative secretary to the Director, October 9, 1943.

Ruth W. Helsley appointed senior clerk-stenographer (CAF-5) October 9, 1943.

E. Harriet Link, clerk-stenographer (CAF-4) transferred from the Library of the Smithsonian Institution October 9, 1943.

Grace C. Griffith appointed librarian for a period of 1 year October 25, 1943.

Elizabeth Hill Maltby, former librarian, trained Miss Griffith for the position of librarian October 25-December 13, 1943.

Thomas R. Fullalove, painter, who was retired on account of disability February 15, 1937, died on November 22, 1943.

Bertie Turner, attendant at the Gallery since November 17, 1920, retired on November 30, 1943.

Ruth W. Helsley, senior clerk-stenographer, resigned on December 4, 1943. She first came to the Gallery on November 22, 1920, resigned on February 28, 1922, and was reinstated on May 5, 1930.

Alice Copeland appointed attendant (CPC-2) December 9, 1943.

E. Harriet Link promoted to senior clerk-stenographer (CAF-5) December 9, 1943.

Grace C. Griffith, librarian, was married to Charles Maxwell Barnett, United States Army Air Forces, on April 15, 1944.

Burns A. Stubbs resigned from the Civil Service position of chief scientific aid (SP-8) April 23, 1944. He was appointed by the Freer Gallery as assistant to the Director on April 24, 1944.

Glen P. Shephard was appointed museum aid (SP-4) from guard (CPC-4) April 24, 1944.

Grace T. Whitney worked intermittently at the Gallery in the Near East section between December 2, 1943 and June 21, 1944.

Other changes in personnel are as follows:

Appointments.—Alfred Hewitt, a guard on the day watch since August 1, 1936, promoted to sergeant (CPC-5) July 1, 1943. Glen P. Shephard, guard (CPC-4), from military furlough, July 1, 1943. Charles W. Frost, guard (CPC-4), by transfer from Airport Detachment No. 5, Gravelly Point, Va., August 27, 1943. Ethel Anderson, charwoman (CPC-2), by transfer from the United States National

Museum, December 9, 1943. George Jonathan, guard (CPC-4), appointed December 15, 1943. Pearl Fisher, charwoman (CPC-2), appointed December 23, 1943. Milton Williams, laborer (CPC-2), appointed May 1, 1944. Victoria L. Dickerson, charwoman (CPC-2), appointed May 4, 1944. George S. Young, cabinetmaker, appointed by the month for special help in the shop, May 8, 1944.

Separations from the service.—George S. Young finished temporary employment as cabinetmaker, November 4, 1943. Julia A. Robinson, charwoman (CPC-2), transferred to the United States National Museum, December 8, 1943. Pearl Fisher, charwoman (CPC-2), resigned March 22, 1944. Walter McCree, laborer (CPC-2), on indefinite furlough for naval duty, April 4, 1944.

Respectfully submitted.

A. G. WENLEY, *Director.*

THE SECRETARY,
Smithsonian Institution.

APPENDIX 5

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY

SIR: I have the honor to submit the following report on the field researches, office work, and other operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1944, conducted in accordance with the act of Congress of June 26, 1943, which provides "* * *" for continuing ethnological researches among the American Indians and the natives of Hawaii and the excavation and preservation of archeologic remains. * * *

During the fiscal year emphasis on activities concerned with Latin America has continued.

Dr. W. D. Strong, Director of the Ethnogeographic Board, planned to return to his duties at Columbia University soon after the close of the fiscal year, and the work of the Board will thereafter be conducted entirely by members of the Bureau staff.

As the war continues and the need for specialized information grows less it is expected that the Bureau may gradually assume more of its normal duties.

SYSTEMATIC RESEARCHES

On January 28, 1944, Dr. M. W. Stirling, Chief of the Bureau, left Washington on the Sixth National Geographic Society-Smithsonian Institution expedition to Mexico. The month of February was spent in the states of Michoacán and Jalisco, where a photographic record was made of lacquer working in Uruapan and vicinity, and of pottery making in Tlaquepaque. Ethnological pictures were made depicting the activities and customs of the Tarascan Indians of Lake Pátzcuaro.

From the beginning of March until the middle of May, an archeological reconnaissance was conducted in southern Veracruz, Tabasco, and Campeche, with the principal objective of finding the extent of the early La Venta culture in this area. Several new sites were located as a result of this survey, and photographic records were made of a number of private archeological collections.

Dr. Stirling returned to Washington on May 22, 1944.

During the year a report by Dr. Stirling, "Stone Monuments of Southern Mexico," was issued as Bulletin 138 of the Bureau.

During the year just passed, Dr. John R. Swanton, ethnologist, completed the reading of proof for Bulletin 137, "The Indians of the Southeastern United States."

A study of the much discussed Norse expeditions to America was undertaken and a manuscript completed embodying the results.

During the course of the year Dr. Swanton furnished to the Navy Department more than 1,000 Indian tribal names and names of prominent Indians, to be used for naming war vessels. Approximately 200 of these have been used.

On June 30, 1944, Dr. Swanton retired from the Bureau after almost 44 years of service.

Dr. John P. Harrington, ethnologist, continuing his American Indian linguistic studies, discovered evidence suggesting that Quechua and Aymara, the languages of the two most highly civilized groups of aboriginal South America, are related to the Hokan stock of western North America. This is the first time that a linguistic relationship has been indicated between North and South America. In addition to this Dr. Harrington has reduced the number of linguistic stocks in South America by establishing the relationship of many groups previously considered to be separate.

Because of his unique knowledge of languages, Dr. Harrington has been called upon daily by the Office of Censorship to translate letters written in little-known languages from all over the world.

During the year several short papers on linguistic subjects have been published in scientific journals.

On July 5, 1943, Dr. Frank H. H. Roberts, Jr., senior archeologist, went to Abilene, Tex., where he spent 5 days investigating a prehistoric Indian burial which had been exposed 21 feet below the surface in a bank of the Clear Fork of the Brazos River by floodwaters and which was in danger of being washed away by a new rise. Studies of the deposits at the site showed that the burial had been made during the closing days of the Pleistocene or the beginning of the Early Recent geologic period about 10,000 years ago. The skeleton was turned over to the division of physical anthropology of the United States National Museum, where it has received careful study and has added to the knowledge of the physical type of the early Texas Indians.

Returning to Washington, Dr. Roberts spent the remainder of the summer and the months of early autumn preparing contributions to, obtaining pictures for, editing the manuscript, and reading proof of a manual, "Survival on Land and Sea," which was prepared for the Publications Branch of the Office of Naval Intelligence, United States Navy, by the Ethnogeographic Board and the staff of the Smithsonian Institution. He later worked on a revision of this manual for a second edition and also served as a consultant for a similar manual being prepared for the Army Air Forces. During this period he also furnished information to several other branches of the armed services and some of the war agencies.

Dr. Roberts also worked on his final report on the excavations at the Lindenmeier Folsom Man site in northern Colorado, a project completed shortly before the outbreak of the war, and also wrote a number of articles for publication in scientific journals. On March 16, 1944, Dr. Roberts was appointed a member of the Smithsonian Institution's Committee on Personnel Utilization and from that date until the close of the fiscal year devoted considerable time to the activities of that committee.

During such periods as the Chief was absent from Washington, Dr. Roberts served as Acting Chief of the Bureau.

On September 1, 1943, Dr. Julian H. Steward, anthropologist, was appointed Director of the Institute of Social Anthropology, an autonomous unit of the Bureau, reporting directly to the Secretary. His work as editor of the *Handbook of South American Indians* also continued concurrently. A brief statement on these two projects will be found later on in this report.

At the beginning of the fiscal year Dr. Alfred Métraux, ethnologist, was teaching in Mexico City, through an arrangement with the National University of Mexico. He returned to duty on August 1, 1943, and assisted Dr. Julian H. Steward in the preparation of the *Handbook of South American Indians*. Dr. Métraux was appointed Assistant Director of the Institute of Social Anthropology on September 18, 1943. He completed four papers for the *Handbook*, and also gathered bibliographical material for several other contributions and assembled notes for the articles of the *Handbook's* fifth volume.

During the fiscal year Dr. Henry B. Collins, Jr., ethnologist, continued his work as Assistant Director of the Ethnogeographic Board. As in the previous year, the activities of the Board for which he was responsible concerned research in connection with regional and other information requested by the Army, Navy, and other war agencies. He represented the Smithsonian Institution and the Ethnogeographic Board as a technical adviser to the Emergency Rescue Equipment Section of the Navy and wrote the Arctic section for the booklet "Survival on Land and Sea." Some 750,000 copies of this official Navy survival manual have been distributed to the fleet and shore stations.

Dr. Collins contributed the sections on geography, history, and anthropology for an article on the Aleutian Islands, which will be published as one of the series of War Background Studies of the Smithsonian Institution.

During such time as was available, Dr. Collins continued his researches on the Eskimo and the southeastern Indians.

Dr. William N. Fenton, ethnologist, continued to serve as research associate of the Ethnogeographic Board. With the assistance of

Miss Mae W. Tucker, he has maintained for the Ethnogeographic Board the world file of area and language specialists, which has grown to include more than 10,000 entries for all continents and island areas. This file has been extensively used by the military and other war agencies in their search for specialized personnel. From this file a series of five studies were prepared, together with maps and indexes, showing domestic sources of photographs on strategic areas of interest particularly to the Navy Department. At the request of the Army Specialized Training Division, the Ethnogeographic Board commenced a survey of area and language teaching in the Army Specialized Training Program and the Civil Affairs Training Schools in 25 American universities and colleges. Dr. Fenton participated in the survey, visiting 13 institutions between December 1943 and March 1944, and since that time has been occupied in writing up observations and preparing reports for the proper offices.

In addition to this work, Dr. Fenton continued his studies on the League of the Iroquois, translating a number of texts collected by J. N. B. Hewitt and A. A. Goldenweiser. Dr. Fenton's publications for the year were: "The Last Passenger Pigeon Hunts of the Cornplanter Senecas" (*with M. H. Deardorff*), and "The Requickenening Address of the Iroquois Condolence Council" (*of J. N. B. Hewitt*), in the *Journal of the Washington Academy of Sciences*; and an obituary, "Simeon Gibson: Iroquois Informant, 1889-1943," in the *American Anthropologist*; also several book reviews and notes in scientific and literary journals.

Since joining the staff in December 1943, Dr. Homer G. Barnett, anthropologist, has served as executive secretary of a committee formed under the sponsorship of the Ethnogeographic Board for the purpose of assembling data upon the existing state of our scientific knowledge of the Pacific Island area. The committee includes representatives of the geological, geographic, linguistic, political science, and anthropological disciplines. As executive secretary Dr. Barnett has served chiefly as organizer and coordinator of the committee's actions. Since some of the committee members are located outside of Washington, considerable correspondence has been necessary as well as meetings both in Washington and New York.

When not engaged in the above activities, Dr. Barnett has worked on the organization of field notes on various Salishan and Northwest Coast tribes, having in project a series of publications stressing cultural change among the Yurok, the Tsimshian, the Yakima, and the Makah. He has just completed one manuscript dealing with the Indian Shaker cult of the northwestern United States.

INSTITUTE OF SOCIAL ANTHROPOLOGY

As stated above, Dr. Julian H. Steward, anthropologist, on September 1, 1943, became Director of the Institute of Social Anthropology, an autonomous unit of the Bureau reporting directly to the Secretary. As Dr. Steward was instructed in the official order establishing the Institute to report to the Secretary of the Smithsonian Institution, there are presented here brief abstracts from Dr. Steward's reports to Dr. Wetmore, Acting Secretary.

The Institute of Social Anthropology was first conceived in July 1942 and a project for its work was placed before the Interdepartmental Committee for Cooperation with the American Republics in August of that year. Its stated purpose was to carry out cooperative training in anthropological teaching and research with the other American republics. For the fiscal year 1944, \$60,000 was made available for the work of the Institute by transfer of funds from the State Department appropriation.

In September 1943 the Director visited Mexico and established the terms of an agreement for the work of the Institute with the authorities of the Escuela Nacional de Antropología and the Instituto Nacional de Antropología e Historia, submitting this to the Department of State in late September. After some months of delay encountered in completing the agreement, Dr. George M. Foster, engaged by the Institute as anthropologist in charge of the work in Mexico, proceeded to that country in May and started work in cooperation with the organizations mentioned above. Dr. Donald D. Brand also represented the Institute in Mexico as cultural geographer.

No formal agreement has yet been entered into for similar work in Peru. Nevertheless, Dr. John Gillin, appointed by the Institute in January 1944 as anthropologist, commenced work in that country on an informal basis. The remaining 6 months of the fiscal year were devoted to reconnaissance and teaching at Cuzco and Trujillo.

A memorandum agreement for cooperative work in Colombia was submitted early in 1944, but at the close of the fiscal year it had not yet been reported out.

A new series in social anthropology entitled "Publications of the Institute of Social Anthropology" was started with two papers, which went to the printer just before the close of the fiscal year. No. 1 was on "Houses and House Use of the Sierra Tarascans," by Ralph L. Beals, Pedro Carrasco, and Thomas McCorkle; No. 2 was entitled "Cherán, a Sierra Tarascan Village," by Ralph L. Beals.

HANDBOOK OF SOUTH AMERICAN INDIANS

The editing of the Handbook of South American Indians, begun some years ago, was continued during the year by Dr. Julian H. Steward after September 1, 1943, under his appointment as Director of the Institute of Social Anthropology. Funds for the preparation of the manuscript are transferred to the Smithsonian Institution from the State Department appropriation for "Cooperation with the American Republics," and the Bureau will pay the cost of publication in its Bulletin series.

Volume 1, "The Marginal Tribes," and volume 2, "The Andean Civilizations," were completed during the year and sent to the printer. The manuscripts of volumes 3 and 4 were nearly completed.

The Handbook is a truly cooperative project, as one-half of the 100 contributors are scientists of the other American republics.

SPECIAL RESEARCHES

Miss Frances Densmore, a collaborator of the Bureau, continued her work on the study of Indian music by writing a manuscript entitled "Omaha Music," with transcriptions of 64 songs. This manuscript was based upon research in Nebraska in 1941 and included re-recordings of several songs that were recorded for Miss Alice C. Fletcher by the same singers. The date of the previous recordings was said to have been 1887 to 1890 and the songs are included in Miss Fletcher's "Study of Omaha Indian Music," published by the Peabody Museum of Harvard University, and in "The Omaha Tribe," by Miss Fletcher and Francis La Flesche, in the Twenty-seventh Annual Report of the Bureau. Many songs in Miss Fletcher's work were recognized by men who had not the tribal right to sing them. The present manuscript includes old songs of Omaha military and social societies, songs connected with the First World War, and songs of legends and the hand game.

Miss Densmore compiled and presented to the Bureau a chronology of her study and presentation of Indian music from 1893 to June 1944. This chronology was based on diaries, scrapbooks, and Reports of the Bureau. During a portion of the year she was engaged in completing the handbook of the Smithsonian-Densmore collection of sound recordings of American Indian music for the National Archives.

EDITORIAL WORK AND PUBLICATIONS

The editorial work of the Bureau continued during the year under the immediate direction of the editor, M. Helen Palmer. There were issued one Annual Report and six Bulletins, as follows:

Sixtieth Annual Report of the Bureau of American Ethnology, 1942-1943. 9 pp.
 Bulletin 133. Anthropological papers, numbers 19-26. ix+615 pp., 34 pls.,
 62 figs.:

- No. 19. A search for songs among the Chitimacha Indians in Louisiana, by Frances Densmore.
- No. 20. Archeological survey on the northern Northwest Coast, by Phillip Drucker; with appendix, Early vertebrate fauna of the British Columbia Coast, by Edna M. Fisher.
- No. 21. Some notes on a few sites in Beaufort County, South Carolina, by Regina Flannery.
- No. 22. An analysis and interpretation of the ceramic remains from two sites near Beaufort, South Carolina, by James B. Griffin.
- No. 23. The eastern Cherokees, by William Harlan Gilbert, Jr.
- No. 24. Aconite poison whaling in Asia and America: An Aleutian transfer to the New World, by Robert F. Helzer.
- No. 25. The Carrier Indians of the Bulkley River: Their social and religious life, by Diamond Jenness.
- No. 26. The quipu and Peruvian civilization, by John R. Swanton.

Bulletin 136. Anthropological papers, numbers 27-32. viii+375 pp., 32 pls.,
 5 figs.:

- No. 27. Music of the Indians of British Columbia, by Frances Densmore.
- No. 28. Choctaw music, by Frances Densmore.
- No. 29. Some ethnological data concerning one hundred Yucatan plants, by Morris Steggerda.
- No. 30. A description of thirty towns in Yucatan, Mexico, by Morris Steggerda.
- No. 31. Some western Shoshoni myths, by Julian H. Steward.
- No. 32. New material from Acoma, by Leslie A. White.

Bulletin 138. Stone monuments of southern Mexico, by Matthew W. Stirling.
 vii+84 pp., 62 pls., 14 figs.

Bulletin 139. An introduction to the ceramics of Tres Zapotes, Veracruz, Mexico,
 by C. W. Welant. xiv+144 pp., 78 pls., 54 figs., 10 maps.

Bulletin 140. Ceramic sequences at Tres Zapotes, Veracruz, Mexico, by Phillip
 Drucker. ix+155 pp., 65 pls., 46 figs.

Bulletin 141. Ceramic stratigraphy at Cerro de las Mesas, Veracruz, Mexico,
 by Phillip Drucker. viii+95 pp., 53 pls., 210 figs.

The following publications were in press at the close of the fiscal
 year:

Bulletin 137. The Indians of the Southeastern United States, by John R.
 Swanton.

Bulletin 142. The contemporary culture of the Cáhita Indians, by Ralph L.
 Beals.

Bulletin 143. Handbook of South American Indians. Julian H. Steward,
 Editor. Volume 1. The Marginal Tribes. Volume 2. The Andean Civilizations.

List of Publications of the Bureau of American Ethnology, with index to
 authors and titles. Revised to June 30, 1944.

Publications distributed totaled 14,903.

In addition to the regular work, the editorial staff of the Bureau
 edited the first two publications of the Smithsonian Institution's
 Institute of Social Anthropology, now in press.

LIBRARY

Accessions during the fiscal year totaled 190. There has been a sharp decrease in accessions owing to war conditions.

The routine work of accessioning and cataloging new material has been kept up to date. About half of the cards withdrawn from the catalog for reclassification have been returned to the catalog, with the new numbers added and subject headings corrected.

The library has been used considerably for the work of the Ethnogeographic Board and other war agencies.

ILLUSTRATIONS

During the year E. G. Cassedy, illustrator, continued the preparation of illustrations, maps, and drawings for the publications of the Bureau and for those of other branches of the Institution.

MISCELLANEOUS

During the course of the year information was furnished by members of the Bureau staff in reply to numerous inquiries concerning the North American Indians, both past and present, and the Mexican peoples of the prehistoric and early historic periods. Various specimens sent to the Bureau were identified and data on them furnished for their owners.

Personnel.—Dr. Julian H. Steward, anthropologist, was appointed Director of the Institute of Social Anthropology, Smithsonian Institution, on September 1, 1943, by transfer from the Bureau, and Dr. Homer G. Barnett was appointed as anthropologist on December 30, 1943, on the Bureau roll, to fill this vacancy. The work on the Handbook of South American Indians was continued under the Interdepartmental Committee for Cooperation with the American Republics after September 1, 1943. Anthony W. Wilding, clerk-stenographer, was appointed Property Officer of the United States National Museum on December 20, 1943, by transfer from the Bureau, and Mrs. Catherine M. Phillips was appointed to fill this vacancy on December 22, 1943, by transfer from the editorial division, Smithsonian Institution. Dr. John R. Swanton, ethnologist, retired on June 30, 1944.

Respectfully submitted.

M. W. STIRLING, *Chief.*

THE SECRETARY,
Smithsonian Institution.

APPENDIX 6

REPORT ON THE INTERNATIONAL EXCHANGE SERVICE

SIR: I have the honor to submit the following report on the activities of the International Exchange Service for the fiscal year ended June 30, 1944.

From the appropriation "General Expenses, Smithsonian Institution" there was allocated for the expenses of the Service, \$26,137.

No money was allotted to the Institution this year by the Department of State for use in mailing packages to Argentina and Brazil, so that the cost of such mailings had to be met from the regular Exchange allotment. These are the only two American countries with which there are no reciprocal arrangements for the exchange of publications under governmental frank.

The number of packages received during the year for distribution at home and abroad was 407,764, a decrease from last year of 105,696. These packages weighed a total of 243,180 pounds, a decrease of 5,468 pounds. This material is classified as follows:

	Packages		Weight	
	Sent abroad	Received from abroad	Sent abroad	Received from abroad
United States parliamentary documents sent abroad.....	303, 103		<i>Pounds</i> 127, 401	<i>Pounds</i>
Publications received in return for parliamentary documents...		737		1, 544
United States departmental documents sent abroad.....	52, 968		43, 617	
Publications received in return for departmental documents...		679		1, 530
Miscellaneous scientific and literary publications sent abroad..	46, 700		62, 768	
Miscellaneous scientific and literary publications received from abroad for distribution in the United States.....		3, 637		6, 320
Total.....	402, 771	4, 993	233, 756	9, 394
Grand total.....	407, 764		243, 180	

Packages are forwarded abroad partly by freight to exchange bureaus for distribution, and partly by mail directly to their destinations. The number of boxes shipped abroad was 649, an increase over last year of 6 boxes. Of these, 385 were for depositories of full sets of United States governmental documents. The number of packages sent by mail was 89,688.

War conditions have made it necessary for the Institution to suspend shipments to many foreign countries. The countries to which shipments were being made at the close of the year were as follows:

Eastern Hemisphere:

Great Britain and Northern Ireland.

Portugal.

Union of Soviet Socialist Republics.

Union of South Africa.

India

Australia.

New Zealand.

Western Hemisphere: All countries.

In the report for 1941 it was stated that the British Museum, Department of Printed Books, had requested the Institution to discontinue the sending of the full set of United States governmental documents for the duration of the war because of the possibility of destruction of the material through bombings of London. About the middle of the current year the British Museum asked that the forwarding of the Government sets be resumed as numerous requests had been received for information contained in many of the documents. Accordingly, all accumulations of official documents for the British Museum were sent and regular transmissions have since been made.

FOREIGN DEPOSITORIES OF GOVERNMENTAL DOCUMENTS

The number of sets of United States official publications received for transmission abroad through the International Exchange Service is 93 (55 full and 38 partial sets). On account of war conditions it is possible at this time to forward only 58 of these sets. The remaining 35 are being withheld for the duration.

During the year Iran and Iraq were added to the list of those countries receiving partial sets. The depository in Iran is the Ministry of Education at Tehran, and in Iraq, Public Library at Baghdad.

The partial-set depository in Afghanistan has been changed to the Library of the Afghan Academy, Kabul. The depository of the partial set sent to Bengal has been changed to Library, Bengal Legislature, Calcutta.

A complete list of the depositories follows. Under present conditions, consignments are forwarded only to those countries listed on tions, consignments are forwarded only to those countries listed above.

DEPOSITORIES OF FULL SETS

ARGENTINA: Dirección de Investigaciones, Archivo, Biblioteca y Legislación Extranjera, Ministerio de Relaciones Exteriores y Culto, Buenos Aires.

- AUSTRALIA:** Commonwealth Parliament and National Library, Canberra.
NEW SOUTH WALES: Public Library of New South Wales, Sydney.
QUEENSLAND: Parliamentary Library, Brisbane.
SOUTH AUSTRALIA: Public Library of South Australia, Adelaide.
TASMANIA: Parliamentary Library, Hobart.
VICTORIA: Public Library of Victoria, Melbourne.
WESTERN AUSTRALIA: Public Library of Western Australia, Perth.
- BELGIUM:** Bibliothèque Royale, Bruxelles.
BRAZIL: Instituto Nacional do Livro, Rio de Janeiro.
CANADA: Library of Parliament, Ottawa.
MANITOBA: Provincial Library, Winnipeg.
ONTARIO: Legislative Library, Toronto.
QUEBEC: Library of the Legislature of the Province of Quebec.
- CHILE:** Biblioteca Nacional, Santiago.
CHINA: Bureau of International Exchange, Ministry of Education, Chungking.
COLOMBIA: Biblioteca Nacional, Bogotá.
COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.
CUBA: Ministerio de Estado, Canje Internacional, Habana.
- CZECHOSLOVAKIA:** Bibliothèque de l'Assemblée Nationale, Prague.
DENMARK: Kongelige Danske Videnskaberne Selskab, Copenhagen.
EGYPT: Bureau des Publications, Ministère des Finances, Cairo.
ESTONIA: Riigirahmatukogu (State Library), Tallinn.
FINLAND: Parliamentary Library, Helsinki.
FRANCE: Bibliothèque Nationale, Paris.
- GERMANY:** Reichsaustauschstelle im Reichsministerium für Wissenschaft, Erziehung und Volksbildung, Berlin, N. W. 7.
PRUSSIA: Preussische Staatsbibliothek, Berlin, N. W. 7.
- GREAT BRITAIN:**
ENGLAND: British Museum, London.
LONDON: London School of Economics and Political Science. (Depository of the London County Council.)
- HUNGARY:** Library, Hungarian House of Delegates, Budapest.
INDIA: Imperial Library, Calcutta.
IRELAND: National Library of Ireland, Dublin.
ITALY: Ministero dell'Educazione Nazionale, Rome.
JAPAN: Imperial Library of Japan, Tokyo.
LATVIA: Bibliothèque d'État, Riga.
- LEAGUE OF NATIONS:** Library of the League of Nations, Geneva, Switzerland.
MEXICO: Dirección General de Información, Secretaría de Gobernación, Mexico, D. F.
- NETHERLANDS:** Royal Library, The Hague.
NEW ZEALAND: General Assembly Library, Wellington.
NORTHERN IRELAND: H. M. Stationery Office, Belfast.
NORWAY: Universitets-Bibliothek, Oslo. (Depository of the Government of Norway.)
- PERU:** Sección de Propaganda y Publicaciones, Ministerio de Relaciones Exteriores, Lima.
POLAND: Bibliothèque Nationale, Warsaw.
PORTUGAL: Biblioteca Nacional, Lisbon.
RUMANIA: Academia Română, Bucharest.

SPAIN: Cambio Internacional de Publicaciones, Avenida de Calvo Sotelo 20, Madrid.

SWEDEN: Kungliga Biblioteket, Stockholm.

SWITZERLAND: Bibliothèque Centrale Fédérale, Berne.

TURKEY: Department of Printing and Engraving, Ministry of Education, Istanbul.

UNION OF SOUTH AFRICA: State Library, Pretoria, Transvaal.

UNION OF SOVIET SOCIALIST REPUBLICS: All-Union Lenin Library, Moscow 115.

UKRAINE: Ukrainian Society for Cultural Relations with Foreign Countries, Kiev.

URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.

VENEZUELA: Biblioteca Nacional, Caracas.

YUGOSLAVIA: Ministère de l'Éducation, Belgrade.

DEPOSITORIES OF PARTIAL SETS

AFGHANISTAN: Library of the Afghan Academy, Kabul.

BOLIVIA: Biblioteca del Ministerio de Relaciones Exteriores y Culto, La Paz.

BRAZIL:

MINAS GERAES: Directoria Geral e Estatística em Minas, Belo Horizonte.

BRITISH GUIANA: Government Secretary's Office, Georgetown, Demerara.

CANADA:

ALBERTA: Provincial Library, Edmonton.

BRITISH COLUMBIA: Provincial Library, Victoria.

NEW BRUNSWICK: Legislative Library, Fredericton.

NOVA SCOTIA: Provincial Secretary of Nova Scotia, Halifax.

PRINCE EDWARD ISLAND: Legislative and Public Library, Charlottetown.

SASKATCHEWAN: Legislative Library, Regina.

CEYLON: Chief Secretary's Office, Record Department of the Library, Colombo.

CHINA: National Library of Peking.

DOMINICAN REPUBLIC: Biblioteca de la Universidad de Santo Domingo, Ciudad Trujillo.

ECUADOR: Biblioteca Nacional, Quito.

GUATEMALA: Biblioteca Nacional, Guatemala.

HAITI: Bibliothèque Nationale, Port-au-Prince.

HONDURAS:

Biblioteca y Archivo Nacionales, Tegucigalpa.

Ministerio de Relaciones Exteriores, Tegucigalpa.

ICELAND: National Library, Reykjavik.

INDIA:

BENGAL: Library, Bengal Legislature, Assembly House, Calcutta.

BIHAR AND ORISSA: Revenue Department, Patna.

BOMBAY: Undersecretary to the Government of Bombay, General Department, Bombay.

BURMA: Secretary to the Government of Burma, Education Department, Rangoon.

PUNJAB: Chief Secretary to the Government of the Punjab, Lahore.

UNITED PROVINCES OF AGRA AND OUDH: University of Allahabad, Allahabad.

IRAN: Imperial Ministry of Education, Tehran.

IRAQ: Public Library, Baghdad.

JAMAICA: Colonial Secretary, Kingston.

LIBERIA: Department of State, Monrovia.

MALTA: Minister for the Treasury, Valletta.

NEWFOUNDLAND: Department of Home Affairs, St. John's.

NICARAGUA: Ministerio de Relaciones Exteriores, Managua.

PANAMA: Ministerio de Relaciones Exteriores, Panama.

PARAGUAY: Ministerio de Relaciones Exteriores, Sección Biblioteca, Asunción.

SALVADOR:

Biblioteca Nacional, San Salvador.

Ministerio de Relaciones Exteriores, San Salvador.

THAILAND: Department of Foreign Affairs, Bangkok.

VATICAN CITY: Biblioteca Apostolica Vaticana, Vatican City, Italy.

INTERPARLIAMENTARY EXCHANGE OF THE OFFICIAL JOURNAL

There are now being sent abroad only 58 copies each of the Congressional Record and Federal Register, the number having been reduced on account of the war from 71, as fully reported on last year. The Library of Congress has arranged to have an extra copy of the Register furnished for transmission to Dr. Fermin Peraza for use in connection with his work as director of several pan-American organizations at Habana, Cuba.

A list of the countries and depositories to which these journals are being forwarded follows:

DEPOSITORIES OF CONGRESSIONAL RECORD AND FEDERAL REGISTER

ARGENTINA:

Biblioteca del Congreso Nacional, Buenos Aires.

Cámara de Diputados, Oficina de Información Parlamentaria, Buenos Aires.

Boletín Oficial de la República Argentina, Ministerio de Justicia e Instrucción Pública, Buenos Aires.

AUSTRALIA:

Commonwealth Parliament and National Library, Canberra.

NEW SOUTH WALES: Library of Parliament of New South Wales, Sydney.

QUEENSLAND: Chief Secretary's Office, Brisbane.

WESTERN AUSTRALIA: Library of Parliament of Western Australia, Perth.

BRAZIL:

Biblioteca do Congresso Nacional, Rio de Janeiro.

AMAZONAS: Arquivo, Biblioteca e Imprensa Publica, Manaus.

BAHIA: Governador do Estado da Bahia, São Salvador.

ESPIRITO SANTO: Presidencia do Estado do Espírito Santo, Victoria.

RIO GRANDE DO SUL: "A Federação," Porto Alegre.

SERGIPE: Biblioteca Publica do Estado de Sergipe, Aracaju.

BRITISH HONDURAS: Colonial Secretary, Belize.

CANADA:

Library of Parliament, Ottawa.

Clerk of the Senate, Houses of Parliament, Ottawa.

CUBA: Biblioteca del Capitolio, Habana.

GREAT BRITAIN: Printed Library of the Foreign Office, London.

GUATEMALA: Biblioteca de la Asamblea Legislativa, Guatemala.

HAITI: Bibliothèque Nationale, Port-au-Prince.

HONDURAS: Biblioteca del Congreso Nacional, Tegucigalpa.

INDIA: Legislative Department, Simla.

IRISH FREE STATE: Dail Eireann, Dublin.

MEXICO:

Dirección General de Información, Secretaría de Gobernación, Mexico, D. F.
Biblioteca Benjamin Franklin, Mexico, D. F.

AGUASCALIENTES: Gobernador del Estado de Aguascalientes, Aguascalientes.

CAMPECHE: Gobernador del Estado de Campeche, Campeche.

CHIAPAS: Gobernador del Estado de Chiapas, Tuxtla Gutierrez.

CHIHUAHUA: Gobernador del Estado de Chihuahua, Chihuahua.

COAHUILA: Periódico Oficial del Estado de Coahuila, Palacio de Gobierno, Saltillo.

COLIMA: Gobernador del Estado de Colima, Colima.

DURANGO: Gobernador Constitucional del Estado de Durango, Durango.

GUANAJUATO: Secretaría General de Gobierno del Estado, Guanajuato.

GUERRERO: Gobernador del Estado de Guerrero, Chilpancingo.

JALISCO: Biblioteca del Estado, Guadalajara.

LOWER CALIFORNIA: Gobernador del Distrito Norte, Mexicali.

MÉXICO: Gaceta del Gobierno, Toluca.

MICHOACÁN: Secretaría General de Gobierno del Estado de Michoacán, Morelia.

MORELOS: Palacio de Gobierno, Cuernavaca.

NAYARIT: Gobernador de Nayarit, Tepic.

NUÉVO LEÓN: Biblioteca del Estado, Monterrey.

OAXACA: Periódico Oficial, Palacio de Gobierno, Oaxaca.

PUEBLA: Secretaría General de Gobierno, Puebla.

QUERÉTARO: Secretaría General de Gobierno, Sección de Archivo, Querétaro.

SAN LUIS POTOSÍ: Congreso del Estado, San Luis Potosí.

SINALOA: Gobernador del Estado de Sinaloa, Culiacán.

SONORA: Gobernador del Estado de Sonora, Hermosillo.

TABASCO: Secretaría General de Gobierno, Sección 3a, Ramo de Prensa, Villahermosa.

TAMAULIPAS: Secretaría General de Gobierno, Victoria.

TLAXCALA: Secretaría de Gobierno del Estado, Tlaxcala.

VERACRUZ: Gobernador del Estado de Veracruz, Departamento de Gobernación y Justicia, Jalapa.

YUCATÁN: Gobernador del Estado de Yucatán, Mérida.

NEW ZEALAND: General Assembly Library, Wellington.

PERU: Cámara de Diputados, Lima.

UNION OF SOUTH AFRICA:

Library of Parliament, Cape Town, Cape of Good Hope.

State Library, Pretoria, Transvaal.

URUGUAY: Diario Oficial, Calle Florida 1178, Montevideo.

VENEZUELA: Biblioteca del Congreso, Caracas.

FOREIGN EXCHANGE AGENCIES

There is given below a list of bureaus or agencies to which consignments are forwarded in boxes by freight when the Service is in full operation. To all countries not appearing in the list, packages are sent to their destinations through the mails. As stated previously, shipments are forwarded during wartime only to those countries listed on page 60.

LIST OF AGENCIES

- ALGERIA, via France.
- ANGOLA, via Portugal.
- AZORES, via Portugal.
- BELGIUM: Service Belge des Échanges Internationaux, Bibliothèque Royale de Belgique, Bruxelles.
- CANARY ISLANDS, via Spain.
- CHINA: Bureau of International Exchange, Ministry of Education, Chungking.
- CZECHOSLOVAKIA: Service des Échanges Internationaux, Bibliothèque de l'Assemblée Nationale, Prague 1-70.
- DENMARK: Service Danois des Échanges Internationaux, Kongelige Danske Videnskabernes Selskab, Copenhagen V.
- EGYPT: Government Press, Publications Office, Bulaq, Cairo.
- FINLAND: Delegation of the Scientific Societies of Finland, Kasärngatan 24, Helsinki.
- FRANCE: Service Français des Échanges Internationaux, 110 Rue de Grenelle, Paris.
- GERMANY: Amerika-Institut, Universitätsstrasse 8, Berlin, N. W. 7.
- GREAT BRITAIN AND IRELAND: Wheldon & Wesley, 721 North Circular Road, Willesden, London, N. W. 2.
- HUNGARY: Hungarian Libraries Board, Ferenciektere 5, Budapest, IV.
- INDIA: Superintendent of Government Printing and Stationery, Bombay.
- ITALY: Ufficio degli Scambi Internazionali, Ministero dell'Educazione Nazionale, Rome.
- JAPAN: International Exchange Service, Imperial Library of Japan, Uyeno Park, Tokyo.
- LATVIA: Service des Échanges Internationaux, Bibliothèque d'État de Lettonie, Riga.
- LUXEMBOURG, via Belgium.
- MADAGASCAR, via France.
- MADEIRA, via Portugal.
- MOZAMBIQUE, via Portugal.
- NETHERLANDS: International Exchange Bureau of the Netherlands, Royal Library, The Hague.
- NEW SOUTH WALES: Public Library of New South Wales, Sydney.
- NEW ZEALAND: General Assembly Library, Wellington.
- NORWAY: Service Norvégien des Échanges Internationaux, Bibliothèque de l'Université Royale, Oslo.
- PALESTINE: Jewish National and University Library, Jerusalem.
- POLAND: Service Polonais des Échanges Internationaux, Bibliothèque Nationale, Warsaw.
- PORTUGAL: Secção de Trocas Internacionais, Biblioteca Nacional, Lisbon.
- QUEENSLAND: Bureau of Exchanges of International Publications, Chief Secretary's Office, Brisbane.
- RUMANIA: Ministère de la Propagande Nationale, Service des Échanges Internationaux, Bucharest.
- SOUTH AUSTRALIA: South Australian Government Exchanges Bureau, Government Printing and Stationery Office, Adelaide.
- SPAIN: Junta de Intercambio y Adquisición de Libros y Revistas para Bibliotecas Públicas, Ministerio de Educación Nacional, Avenida Calvo Sotelo, 20, Madrid.
- SWEDEN: Kungliga Biblioteket, Stockholm.

SWITZERLAND: Service Suisse des Échanges Internationaux, Bibliothèque Centrale Fédérale, Berne.

TASMANIA: Secretary to the Premier, Hobart.

TURKEY: Ministry of Education, Department of Printing and Engraving, Istanbul.

UNION OF SOUTH AFRICA: Government Printing and Stationery Office, Cape Town, Cape of Good Hope.

UNION OF SOVIET SOCIALIST REPUBLICS: International Book Exchange Department, Society for Cultural Relations with Foreign Countries, Moscow, 58.

VICTORIA: Public Library of Victoria, Melbourne.

WESTERN AUSTRALIA: Public Library of Western Australia, Perth.

YUGOSLAVIA: Section des Échanges Internationaux, Ministère des Affaires Étrangères, Belgrade.

M. A. Tolson, who was appointed under the Smithsonian in March 1881, resigned December 31, 1943, after having been connected with the Institution over 62 years. Mr. Tolson was retired from the government roll in 1934, but has since been employed by the Smithsonian Institution. He continued to perform his regular duties until his resignation.

Clayton L. Polley was, at his own request, retired July 1, 1943. Mr. Polley was a veteran of the volunteer forces of the United States, having served in the Spanish-American war and the Philippine Insurrection.

Paul M. Carey, who enlisted in the Army in August 1942 and who was discharged therefrom on account of disability, was, owing to that condition, retired from the Exchanges February 24, 1944.

Respectfully submitted.

F. E. GASS, *Acting Chief Clerk.*

THE SECRETARY,
Smithsonian Institution.

APPENDIX 7

REPORT ON THE NATIONAL ZOOLOGICAL PARK

SIR: I have the honor to submit the following report on the operations of the National Zoological Park for the fiscal year ended June 30, 1944.

The regular appropriation made by Congress was \$277,130, of which \$34,732 was expended for overtime under the special legislation in effect for this purpose.

GROUND, BUILDINGS, AND ENCLOSURES

The primary function of the Zoo is to maintain and exhibit its collection of animals. To accomplish this under wartime conditions, it has been necessary to limit other activities strictly to maintenance work. No extensive improvements have been made during the year, and because of the difficulty in obtaining critical materials, even the maintenance work has frequently been of a temporary nature. The gates of the Zoo have been open from daylight to dark, and many visitors come to the Park after their working hours. In general, the Park and the collection are in good condition and continue to be used and appreciated by large numbers of visitors.

PERSONNEL

There has been a fairly consistent shortage of manpower in the Zoo of about 20 percent. This has necessitated the employment of temporary labor when it could be obtained, which has thrown a heavy burden onto supervisors to whom such untrained personnel was assigned. The additional supervisory burden has been well carried out, with the result that the care of the Park and of the animals has not been seriously neglected.

On December 31, Head Keeper W. H. Blackburne retired. For 17 years past the retirement age he had been retained by Executive order, and on December 31 completed service of 53 years. He came to the Zoo in 1891 as Keeper, and was made Head Keeper the following year. In 1913, accompanied by Mrs. Blackburne, he went to Egypt to bring back a collection from the zoo at Gizah. Jumbina, the National Zoo's large African elephant, was one of the specimens he brought back; also the pair of cheetahs that lived in the Zoo for nearly 15

years. On his retirement the Smithsonian Institution appointed Mr. Blackburne consultant to the Director for life. In his more than half a century of continuous service, Mr. Blackburne saw the Zoo grow from the original lot of 124 specimens that he brought to the Park from the Smithsonian grounds in a wagon borrowed from the Humane Society to its present size.

WARTIME PROBLEMS

All zoos have faced wartime difficulties in obtaining food and supplies. The National Zoo, however, has received valuable assistance from the managers of some of the large Safeway, A. and P., Giant, and other stores, who have put aside for the Zoo trimmings from vegetables. These are picked up by truck each day and provide the Zoo with greens and certain types of vegetables. Through the United States Marshal's Office there have been obtained considerable quantities of food condemned for one reason or another as not fit for human consumption, including several tons of peanuts, quantities of soy beans, and other products, which have been of material aid.

ATTENDANCE

The attendance for the year was:

July -----	172, 100	February -----	53, 200
August -----	204, 500	March -----	97, 450
September -----	228, 500	April -----	207, 982
October -----	142, 750	May -----	269, 500
November -----	143, 400	June -----	180, 000
December -----	42, 850		
January -----	72, 300	Total -----	1, 803, 532

Although no actual tabulation was made, it was apparent that military and naval personnel constituted a very substantial proportion of the total number of visitors.

There has been a good attendance from various schools and groups who have come by whatever means of transportation were available. It is interesting to note that the number of visitors is more even throughout the week than hitherto, although naturally the attendance reaches its peak on Saturday afternoons, Sundays, and holidays. The number of family picnic parties has greatly increased.

Medical groups have come to the Zoo for the purpose of studying certain types of animals, and the Zoo office receives many requests from the War and Navy Departments and other agencies of the Government for information on biological problems. The Zoo continues to be a regular study ground for art and biology classes, as well as a focal point for inquiries about animals by mail, by telephone, and in person.

ACQUISITION OF SPECIMENS

The animal market has naturally been restricted by the small number of shipments being made from abroad, but a moderate number of desirable specimens have been obtained by purchase or exchange. Among these are a trio of Dama wallabies, the two females of which have produced young since their arrival from the San Diego Zoological Society; a Diana monkey, also from the San Diego Zoological Society; a pair of cotton-headed marmosets, a pair of scarlet cocks-of-the-rock, and a young male jaguar.

GIFTS

Through the Army a number of interesting and valuable specimens have been obtained. Among these are a pair of those rare birds, the kagus, presented by the Free French Government of New Caledonia through Lt. Gen. A. M. Patch and brought to Washington by Lt. John H. Fulling while on leave. On a subsequent voyage, Lieutenant Fulling obtained for the Zoo a pair of flying phalangers and a fine carpet python.

The Army of the U. S. S. R. presented to the Persian Gulf Command, United States Army, through Maj. Gen. Donald H. Connolly, a young Russian bear from the southern Caucasus. This bear, "Mischa," was brought from Persia to Washington under the care of Lt. A. J. Miller.

From the Medical Section, India China Wing, Air Transport Command, through Col. Don Flickinger, came a collection of Indian reptiles, including cobras, kraits, Russell's vipers and a monitor lizard. These were brought to Washington by Corp. Wesley H. Dickinson.

Another interesting addition was a baby howling monkey.

A complete list of donors and their gifts follows:

DONORS AND THEIR GIFTS

- W. Alderson, Washington, D. C., 2 Pekin ducks.
- Ord Alexander, Washington, D. C., red-bellied turtle.
- Army of the U. S. S. R., through Commanding General, Persian Gulf Command, Maj. Gen. Donald H. Connolly, U. S. Army, Old World brown bear.
- W. H. Aughinbaugh, Arlington, Va., 3 Reeves' pheasants.
- Mrs. C. A. Baker, Washington, D. C., alligator.
- Jack Baldwin, Washington, D. C., alligator.
- George Ballou, Bethesda, Md., raccoon, short-tailed shrew, sparrow hawk, 30 white mice, crow, fence lizard.
- Mrs. Nell Barger, Washington, D. C., horned lizard.
- Dr. Paul Bartsch, Washington, D. C., chain or king snake.
- Mrs. G. N. Bates, Alexandria, Va., raccoon.
- J. H. Benn, Silver Spring, Md., worm snake.
- Mr. Berg, Fredericksburg, Va., red fox.
- Mrs. John P. Bressler, Bethesda, Md., nine-banded armadillo.

- James G. Brunzos, Washington, D. C., 2 Pekin ducks.
 S. M. Call, Mocksville, N. C., through North Carolina State Museum, Raleigh, N. C., albino opossum.
 Donald A. Campbell, Chapel Hill, N. C., vervet monkey.
 T. L. Canby, Silver Spring, Md., barn owl.
 Dr. H. J. Carter, Washington, D. C., great blue heron.
 Miss Margaret Carter and Miss Doris M. Rice, Washington, D. C., screech owl.
 Miss Frances Chatfield, Washington, D. C., alligator.
 Peter Chittick, McLean, Va., spotted turtle, 3 milk snakes.
 Robert Claggett, Landover, Md., Pekin duck.
 Dr. Marie B. Clark, Cardozo High School, Washington, D. C., garter snake, hog-nosed snake.
 Tom Collingwood, Washington, D. C., tarantula.
 Mrs. Edward Costello, Washington, D. C., red fox.
 K. L. Curtis, Washington, D. C., raccoon.
 Gordon Dalger, Washington, D. C., 2 Cumberland terrapins.
 James Daphney, Washington, D. C., 2 alligators.
 Claudine DeHaven, Glasgow, Va., corn snake, black snake.
 Glenn Dixon, Washington, D. C., red-tailed hawk.
 Joanne V. Dyke, Washington, D. C., anolla.
 J. E. Ennis, Washington, D. C., barn owl.
 Colonel Evans (address unrecorded), red-tailed hawk.
 William L. Foster, Rockville, Md., barn owl.
 F. F. Fox, Hyattsville, Md., 2 box turtles.
 John Francis, Jr., Washington, D. C., opossum.
 Mrs. Jean B. Fraser, Takoma Park, D. C., 5 American toads.
 Free French Government of New Caledonia, through Lt. Gen. A. M. Patch, U. S. Army, 2 kagus.
 Mrs. Freeman, Washington, D. C., ring-necked pheasant.
 Lt. John H. Fulling, U. S. Army, carpet python, 2 flying phalangiers.
 Stephen Gatti, Washington, D. C., sparrow hawk.
 Gordon Gaver, Thurmont, Md., indigo snake.
 William C. Gawler, Bethesda, Md., 3 Pekin ducks.
 Roger Grannin, Washington, D. C., white rabbit.
 Mrs. William S. Green, through C. Purcell McCue, Appledore Orchard, Greenwood, Va., 2 sika deer.
 Mrs. Charles Greer, Alexandria, Va., 3 Pekin ducks.
 Granville Gude, Washington, D. C., alligator.
 Willie Haltzman, Alexandria, Va., 2 Pekin ducks.
 John N. Hamlet, Fish and Wildlife Service, College Park, Md., 4 meadow mice, 2 northern ravens, 7 pine lizards, 2 blue-tailed skinks, 4 six-lined race runners, pilot black snake.
 Ernest O. Hammersla, Washington, D. C., howling monkey.
 Mrs. H. Hanford, Washington, D. C., 3 canaries.
 Maj. D. Elmo Hardy, U. S. A., 1 Hooock gibbon.
 Richard A. Harman, Alexandria, Va., alligator.
 J. W. Harrison, Mt. Rainier, Md., 2 Pekin ducks.
 Richard T. Heckman, Washington, D. C., 2 white mice.
 Dr. Roy Hertz, National Institute of Health, Bethesda, Md., 18 American toads.
 Mrs. Hibben, Vienna, Va., pilot snake.
 Thomas M. Hopkins, Laurel, Md., water snake, snapping turtle.
 Thomas M. Hopkins and Clyde T. Miles, Jr., Laurel, Md., 3 snapping turtles, spotted turtle, 2 box turtles.
 C. S. Howell, Remington, Va., guinea pigs.

- Gordon L. Jessup, Potomac Heights, D. C., black snake.
 Miss J. M. Jones, Washington, D. C., yellow-naped parrot.
 Mrs. W. A. Justice, Edgewater, Md., double yellow-headed parrot.
 Mrs. Kanthal, Washington, D. C., white squirrel.
 James G. Keller, Washington, D. C., alligator.
 Alfred Kendall, Washington, D. C., cardinal.
 Mrs. I. A. Kulazev, Silver Spring, Md., Cuban conure.
 Mrs. Alta Brill Kremer, Maurertown, Va., 2 Pekin ducks.
 Mrs. Martha Lawty, Washington, D. C., Texas horned lizard.
 Ralph D. Lindsey, Silver Spring, Md., snapping turtle.
 Miss Margaret Love, R. R., Leon, Kans., great horned owl.
 Mrs. Lorraine Lowe, Washington, D. C., gray fox.
 Francine Lee Lyons, Washington, D. C., Pekin duck.
 M. K. Macknet, Takoma Park, Md., pilot snake.
 Medical Section, India China Wing, Air Transport Command, through Col. Don
 Flickinger, M. C., king cobra, Indian cobra, banded krait, common krait,
 2 monitors, 2 tree snakes, Russell's viper, 2 rat snakes, 5 pythons.
 Mrs. John C. Meikle, Washington, D. C., 2 zebra finches.
 George J. Merrick, Washington, D. C., barn owl.
 W. H. Meserole, Washington, D. C., black-crowned night heron.
 B. Miller, Washington, D. C., horned lizard.
 Billy Monroe, Washington, D. C., opossum.
 Benjamin Muller, Washington, D. C., pilot black snake.
 National Capital Parks, Washington, D. C., water snake, tadpoles, *Gambusia*
holbrooki.
 Harry Neuman, Washington, D. C., 2 alligators.
 Fred Orsinger, Fish and Wildlife Service, Washington, D. C., 4 hellbenders,
 10 diamond-back terrapins, mud turtle, 4 mudpuppies.
 Joseph Pignataro, Washington, D. C., 6 ring-necked snakes.
 Freeman Pollock, Washington, D. C., timber rattlesnake.
 Scott Price, Washington, D. C., green racer.
 Anna M. Rager, Washington, D. C., 3 paradise fish, three-spot gourami, 4 blood-
 fins, 100 Trinidad guppies, catfish, 300 snails.
 Miss Anna Rees, Washington, D. C., Pekin duck, mallard duck.
 R. H. Riggs, Chevy Chase, Md., 2 Pekin ducks.
 Lt. Laurance S. Rockefeller, Washington, D. C., European goldfinch, white
 zebra finch.
 Mrs. M. L. Rue, Washington, D. C., 4 muscovy ducks.
 Migual A. Ruiz, Washington, D. C., hog-nosed snake.
 D. R. Sampson, Brentwood, Md., 2 red-shouldered hawks.
 Miss Eugenia Sasa, Washington, D. C., grass parakeet.
 Miss Katherine Sater, Washington, D. C., black snake.
 Daniel Schroeder, Washington, D. C., 2 blue tanagers, 3 Pekin robins, 2 diamond
 doves, Cuban bullfinch.
 Alfred L. Schwoser, Washington, D. C., red fox.
 Sandra Seymour, Riverdale, Md., great horned owl.
 Charles P. Shaeffer, Jr., West Haven, Md., alligator.
 Pfc. A. W. Sharer, United States Army, pilot snake, black snake, 2 copperheads,
 2 blue racers.
 Patsy and Linda Shaw, Washington, D. C., alligator.
 Robert B. Sherfy, Washington, D. C., screech owl.
 Robert Shosteck, Washington, D. C., 2 fence lizards, spotted turtle.

Mrs. J. R. Skinner, Washington, D. C., grass parakeet.
 David W. E. Smith, Washington, D. C., De Kay's snake.
 Mrs. W. R. Smith, Cottage City, Md., 3 ring-necked doves.
 Melvln Snyder, Washington, D. C., Cumberland terrapin.
 Mrs. Rebecca Spittler and Dian Suunbrun, Bethesda, Md., 4 Pekin ducks.
 K. H. Spivey, Washington, D. C., Pekin duck.
 Mrs. L. D. Staver, Washington, D. C., barred owl.
 Mrs. George Strawbridge, Washington, D. C., alligator.
 Ralph Swiggard, Washington, D. C., worm snake.
 Mrs. Taylor (address unrecorded), 5 opossums.
 Edward M. Traylor, Washington, D. C., titi monkey.
 James H. Turner, Dunn Loring, Va., coatimundi.
 Dr. H. R. van Houten, Bethesda, Md., garter snake.
 Ralph C. Wainoskey, United States Army, rhesus monkey.
 Frank J. Walker, Arlington, Va., 2 flying squirrels.
 R. E. Walker, United States Navy, Hydrographic Office, Washington, D. C., painted turtle, diamond-back terrapin, praying mantis.
 T. Wampler, Washington, D. C., 2 crows.
 Ward Farms, Amelia Court House, Va., red fox.
 Theodore Weiner, Washington, D. C., pine lizard.
 Mrs. H. J. Wells, Washington, D. C., diamond-back terrapin.
 Richard Wells, Washington, D. C., desert tortoise.
 J. A. Wheeler, Washington, D. C., sparrow hawk.
 J. H. White, Washington, D. C., gray squirrel.
 Margie, Mary Lu, and Juse Alleen Wilkin, Washington, D. C., cottontail rabbit.
 C. W. Williamson, Washington, D. C., cottonmouth moccasin.
 Ray E. Wooldridge, Washington, D. C., alligator.
 J. C. Wright, Washington, D. C., wood frog.
 (Donor unknown), 2 bobwhites.

NATURAL REPRODUCTION

Four sets of twins of the common marmoset were born during the year.

A cub was born dead to a pair of Polar and Alaska brown bear hybrids which were born in the National Zoological Park in 1936.

Births and hatchings during the year included:

MAMMALS

Scientific name	Common name	Number
<i>Acerocidia indica</i>	Asiatic tapir.....	1
<i>Ammotragus leervia</i>	Aoudad.....	5
<i>Bibos paurus</i>	Gaur.....	1
<i>Bison bison</i>	Bison.....	1
<i>Boa indicus</i>	Zebu.....	1
<i>Boa taurus</i>	British Park cattle.....	1
<i>Callithrix jacchus</i>	Common marmoset.....	8
<i>Camelus bactrianus</i>	Bactrian camel.....	1
<i>Cercopithecus aethiops sabaeus</i>	Green guenon.....	1
<i>Cervus canadensis</i>	Elk.....	1
<i>Choeropsis liberiensis</i>	Pigmy hippopotamus.....	1

<i>Dama dama</i>	{ Fallow deer.....	2
	{ White fallow deer.....	6
<i>Dasyprocta croconota prymnolopha</i>	Agouti.....	1
<i>Dolichotis patagona</i>	Patagonian cavy.....	2
<i>Felis concolor</i>	Puma.....	4
<i>Hemitragus jemlahicus</i>	Tahr.....	1
<i>Microtus pennsylvanicus</i>	Meadow mouse.....	4
<i>Myocastor coypu</i>	Coypu.....	5
<i>Nasua narica</i>	Coatimundi.....	5
<i>Neotoma floridana attwateri</i>	Round-tailed wood rat.....	3
<i>Oncifelis geoffroyi</i>	Geoffroy's cat.....	2
<i>Ovis aries</i>	Woolless or Barbados sheep.....	1
<i>Procyon lotor</i>	Black raccoon.....	1
<i>Thalarcos</i> X <i>Ursus</i>	Hybrid bear.....	1

BIRDS

<i>Anas platyrhynchos</i>	Mallard duck.....	70
<i>Branta canadensis</i>	Canada goose.....	50
<i>Branta canadensis occidentalis</i>	White-cheeked goose.....	20
<i>Cairina moschata</i>	Muscovy duck.....	8
<i>Fulica americana</i>	American coot.....	10
<i>Larus novaehollandiae</i>	Silver gull.....	2
<i>Nycticorax nycticorax naevius</i>	Black-crowned night heron.....	18
<i>Turtur risorius</i>	Ring-necked dove.....	2

REPTILES

<i>Agkistrodon mokeson</i>	Copperhead snake.....	8
<i>Gerrhonotus coeruleus principis</i>	Alligator lizard.....	1
<i>Natrix septemvittata</i>	Queen or moon snake.....	15
<i>Natrix sipedon</i>	Banded water snake.....	51
<i>Natrix taxapilota</i>	Brown water snake.....	39
<i>Thamnophis sirtalis</i>	Midwest garter snake.....	12

LOSSES

Losses include the African rhinoceros, which died after 13 years in the Zoo; a slow loris, after 5 years and 10 months; a mandrill, after 18 years and 7 months; and the maned wolf, after 10 years and 6 months.

A scarlet ibis died after 19 years 11 months; a roseate spoonbill, after 9 years.

A large reticulated python, deposited for exhibition by Clif Wilson, died during the winter. A cast has been made of this snake for permanent exhibition in the United States National Museum. When the dead snake was sent to the Museum, it measured 24 feet 8 inches. Since 8 or 10 inches of the tail was missing, this specimen was well over 25 feet in length, and the dead body weighed 305 pounds, making it one of the largest snakes ever exhibited.

Statement of accessions

How acquired	Mammals	Birds	Reptiles	Amphibians	Fishes	Arachnids	Invertebrates	Total
Presented.....	67	85	122	28	14	1	1	318
Born or hatched.....	73	180	126					379
Received in exchange.....	6	41	34	14				95
Purchased.....	15	23	4	35				77
On deposit.....	23	9	25					57
Collected in the Park.....	1							1
Total.....	185	338	311	77	14	1	1	927

Summary

Animals on hand July 1, 1943.....	2,435
Accessions during the year.....	927

Total animals in collection during year.....	3,362
Removals from collection by death, exchange, and return of animals on deposit.....	736

In collection June 30, 1944.....	2,626
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Status of collection

Class	Species and sub-species	Individuals	Class	Species and sub-species	Individuals
Mammals.....	210	677	Arachnids.....	2	5
Birds.....	312	909	Insects.....	1	100
Reptiles.....	114	447			
Amphibians.....	20	120	Total.....	656	2,626
Fishes.....	37	368			

A list of the animals in the collection follows:

ANIMALS IN THE NATIONAL ZOOLOGICAL PARK JUNE 30, 1944

MAMMALS

MARSUPIALIA

Scientific name	Common name	Number
Didelphidae:		
<i>Didelphis virginiana</i>	Opossum.....	4
Phalangeridae:		
<i>Petaurus breviceps</i>	Lesser flying phalanger.....	2
<i>Petaurus norfolcensis</i>	Australian flying phalanger.....	2
<i>Trichosurus vulpecula</i>	Vulpine or brush-tailed opossum.....	1
Macropodidae:		
<i>Dendrolagus inustus</i>	New Guinea tree kangaroo.....	2
<i>Dendrolagus inustus fuscus</i>	Finsche's tree kangaroo.....	3
<i>Macropus major</i>	Great gray kangaroo.....	1
<i>Thylogale eugentii</i>	Dama wallaby.....	5
Phascolomyidae:		
<i>Vombatus ursinus</i>	Flinders Island wombat.....	1

INSECTIVORA

Scientific name	Common name	Number
Soricidae:		
<i>Blarina brevicauda</i>	Short-tailed shrew.....	1

CARNIVORA

Felidae:

<i>Acinonyx jubatus</i>	Cheetah.....	1
<i>Felis chaus</i>	Jungle cat.....	1
<i>Felis concolor</i>	Puma.....	5
<i>Felis concolor patagonica</i>	Patagonian puma.....	1
<i>Felis concolor</i> × <i>Felis concolor patagonica</i>	North American × South American puma.....	4
<i>Felis leo</i>	Lion.....	6
<i>Felis onca</i>	{ Jaguar.....	5
	{ Black jaguar.....	2
<i>Felis pardalis</i>	Ocelot.....	3
<i>Felis pardus</i>	{ Indian leopard.....	3
	{ Black Indian leopard.....	2
<i>Felis tigris</i>	Bengal tiger.....	2
<i>Felis tigris longipilis</i>	Siberian tiger.....	1
<i>Felis tigris sumatrac</i>	Sumatran tiger.....	4
<i>Lynx rufus</i>	Bay lynx.....	2
<i>Lynx rufus baileyi</i>	Bailey's lynx.....	1
<i>Lynx vinta</i>	Bobcat.....	1
<i>Neofelis nebulosa</i>	Clouded leopard.....	1
<i>Oncifelis geoffroyi</i>	Geoffroy's cat.....	4
<i>Profelis temminckii</i>	Golden cat.....	3

Viverridae:

<i>Arctictis binturong</i>	Binturong.....	2
<i>Civettictis civetta</i>	African civet.....	1
<i>Myonax sanguineus</i>	Dwarf civet.....	1
<i>Paradoxurus hermaphroditus</i>	Small-toothed palm civet.....	1

Hyaenidae:

<i>Crocuta crocuta germinans</i>	East African spotted hyena.....	1
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Canidae:

<i>Canis latrans</i>	Coyote.....	2
<i>Canis latrans</i> × <i>familiaris</i>	Coyote and dog hybrid.....	1
<i>Canis lupus nubilus</i>	Plains wolf.....	2
<i>Canis rufus</i>	Texas red wolf.....	5
<i>Canis javanicus sumatrensis</i>	Sumatran wild dog.....	1
<i>Dusicyon culpaeus</i>	South American fox.....	2
<i>Dusicyon (Cerdocyon) thous</i>	South American fox.....	1
<i>Nyctereutes procyonoides</i>	Raccoon dog.....	2
<i>Urocyon cinereoargenteus</i>	Gray fox.....	9
<i>Vulpes fulva</i>	Red fox.....	11

Procyonidae:

<i>Nasua narica</i>	Coatimundi.....	10
<i>Nasua nelsoni</i>	Nelson's coatimundi.....	1
<i>Potos flavus</i>	Kinkajou.....	7
	{ Raccoon.....	5
<i>Procyon lotor</i>	{ Black raccoon.....	1
	{ Albino raccoon.....	1

CAENIVORA—continued

Scientific name	Common name	Number
Bassariscidae:		
<i>Bassariscus astutus</i>	Ring-tail or cacomistle.....	3
Mustelidae:		
<i>Arctonyx collaris</i>	Hog badger.....	1
<i>Grissonella huronae</i>	Grisson.....	1
<i>Lutra canadensis vago</i>	Florida otter.....	1
<i>Lutra (Micraonyx) cinerea</i>	Small-clawed otter.....	1
<i>Martes (Lampropus) flavigula henrici</i>	Asiatic marten.....	1
<i>Meles meles leptorhynchus</i>	Chinese badger.....	1
<i>Mellivora capensis</i>	Ratel.....	1
<i>Mephitis mephitis nigra</i>	Skunk.....	4
<i>Mustela campestris</i>	Plains least weasel or ermine.....	1
<i>Mustela eversmanni</i>	Ferret.....	2
<i>Tayra barbara barbara</i>	White tayra.....	2
<i>Tayra barbara senilis</i>	Gray-headed tayra.....	1
Ursidae:		
<i>Euarctos americanus</i>	Black bear.....	5
<i>Euarctos tibetanus</i>	Himalayan bear.....	2
<i>Helarctos malayanus</i>	Malay or sun bear.....	1
<i>Melursus ursinus</i>	Sloth bear.....	1
<i>Thalarcos maritimus</i>	Polar bear.....	3
<i>Thalarcos maritimus</i> × <i>Ursus middendorffi</i>	Hybrid bear.....	4
<i>Tremarctos ornatus</i>	Spectacled bear.....	1
<i>Ursus arctos</i>	European brown bear.....	1
<i>Ursus arctos meridionalis</i>	European brown bear.....	1
<i>Ursus gyas</i>	Alaska Peninsula bear.....	3
<i>Ursus middendorffi</i>	Kodiak bear.....	3
<i>Ursus sitkensis</i>	Sitka brown bear.....	3

PINNIPEDIA

Otariidae:		
<i>Zalophus californianus</i>	Sea lion.....	2
Phocidae:		
<i>Phoca vitulina richardii</i>	Pacific harbor seal.....	3

PRIMATES

Lemuridae:		
<i>Lemur mongoz</i>	Mongoose lemur.....	2
Callitrichidae:		
<i>Callithrix jacchus</i>	White-tufted marmoset.....	8
<i>Callithrix penicillata</i>	Black-tufted marmoset.....	5
<i>Tamarin (Oedipomidas) geoffroyi</i>	Geoffroy's tamarin.....	1
<i>Tamarin midas</i>	Yellow-banded tamarin.....	4
<i>Tamarin (Oedipomidas) oedipus</i>	Cotton-top tamarin.....	3
<i>Tamarin (Leontocebus) rosalia</i>	Lion-headed or golden marmoset.....	1
Saimiridae:		
<i>Saimiri sciurea</i>	Titl or squirrel monkey.....	2

PRIMATES—CONTINUED

Scientific name	Common name	Number
Cebidae:		
<i>Alouatta palliata mexicana</i>	Howling monkey.....	1
<i>Aotus trivirgatus</i>	Douroucoul or owl monkey.....	6
<i>Ateles vellerosus</i>	Spider monkey.....	9
<i>Cebus apella</i>	Gray capuchin.....	2
<i>Cebus capucinus</i>	White-throated capuchin.....	2
<i>Cebus fatuellus</i>	Weeping capuchin.....	5
<i>Lagothrix lagothricha</i>	Woolly monkey.....	1
Cercopithecoidea:		
<i>Cercopithecus aethiops pygerythrus</i>	Vervet guenon.....	1
<i>Cercopithecus aethiops sabaensis</i>	Green guenon.....	6
<i>Cercopithecus diana</i>	Diana monkey.....	1
<i>Cercopithecus diana roloway</i>	Roloway monkey.....	1
<i>Cercopithecus neglectus</i>	De Brazza's guenon.....	1
<i>Cercopithecus nictitans petaurista</i>	Lesser white-nosed guenon.....	1
<i>Cercopithecus sp</i>	West African guenon.....	1
<i>Gymnopys maurus</i>	Moor macaque.....	1
<i>Macaca fuscata</i>	Japanese macaque.....	2
<i>Macaca irus mordax</i>	Javan macaque.....	6
<i>Macaca mulatta</i>	Rhesus macaque.....	6
<i>Macaca mulatta lasiotis</i>	Chinese macaque.....	1
<i>Macaca nemestrina</i>	Pig-tailed macaque.....	2
<i>Macaca sinica</i>	Toque or bonnet macaque.....	1
<i>Macaca speciosa</i>	Red-faced macaque.....	1
<i>Mandrillus sphinx</i>	Mandrill.....	2
<i>Papio comatus</i>	Chacma.....	1
<i>Papio cynocephalus</i>	Golden baboon.....	1
Hylobatidae:		
<i>Hylobates agilis</i>	Sumatran gibbon.....	1
<i>Hylobates hoolock</i>	Hoolock gibbon.....	1
<i>Hylobates lar pileatus</i>	Black-capped gibbon.....	1
<i>Symphalangus syndactylus</i>	Slamang gibbon.....	1
Pongidae:		
<i>Pan troglodytes</i>	Chimpanzee.....	2
<i>Pan troglodytes verus</i>	West African chimpanzee.....	3
<i>Pongo abelli</i>	Sumatran orangutan.....	1
<i>Pongo pygmaeus</i>	Bornean orangutan.....	2

RODENTIA

Sciuridae:		
<i>Citellus townsendii</i>	Soft-haired ground squirrel.....	1
<i>Citellus tridecemlineatus</i>	13-lined ground squirrel.....	2
<i>Cynomys ludovicianus</i>	Plains prairie dog.....	55
<i>Glaucomys volans</i>	Flying squirrel.....	6
<i>Marmota monax</i>	Woodchuck or ground hog.....	7
<i>Sciurus carolinensis</i>	Eastern gray squirrel (albino).....	1
<i>Sciurus flaysoni</i>	Lesser white squirrel.....	3
<i>Tamias striatus</i>	Eastern chipmunk.....	1
Heteromyidae:		
<i>Dipodomys merriami</i>	Merriam's kangaroo rat.....	1
<i>Dipodomys ordii</i>	Ord's kangaroo rat.....	3

RODENTIA—continued

Scientific name	Common name	Number
Cricetidae:		
<i>Mesocricetus auratus</i>	Golden hamster.....	15
<i>Microtus pennsylvanicus</i>	Meadow mouse.....	11
<i>Neotoma floridana attenuata</i>	Round-tailed wood rat.....	8
<i>Onychomys leucogaster</i>	Grasshopper mouse.....	1
<i>Peromyscus crinitus auripectus</i>	Golden-breasted mouse.....	1
<i>Peromyscus leucopus</i>	White-footed or deer mouse.....	2
<i>Peromyscus truei</i>	True's white-footed mouse.....	1
<i>Sigmodon hispidus</i>	Cotton rat.....	2
Muridae:		
<i>Mus musculus</i>	White and other domestic mice.....	8
<i>Rattus alexandrinus</i>	Roof rat and black rat.....	1
<i>Rattus norvegicus</i>	White and pied-colored rats.....	2
Hystriidae:		
<i>Acanthion brachyurum</i>	Malay porcupine.....	3
<i>Atherurus africanus</i>	West African brush-tailed porcupine.....	2
<i>Hystrix galeata</i>	African porcupine.....	1
<i>Thecurus crassispinus sumatrae</i>	Thick-spined porcupine.....	1
Myocastoridae:		
<i>Myocastor coypu</i>	Coypu.....	16
Cuniculidae:		
<i>Cuniculus paca virgatus</i>	Central American paca.....	1
Dasyproctidae:		
<i>Dasyprocta</i>	Speckled agouti.....	4
<i>Dasyprocta croconota prymnolopha</i>	Agouti.....	2
Cavidae:		
<i>Cavia porcellus</i>	{ Guinea pig.....	16
	{ Angora guinea pig.....	1
<i>Dolichotis patagona</i>	Patagonian cavy.....	5
Hydrochoeridae:		
<i>Hydrochoerus hydrochoerus</i>	Capybara.....	1

LAGOMORPHIA

Leporidae:		
<i>Oryctolagus cuniculus</i>	Domestic rabbit.....	13

ARTIODACTYLA

Bovidae:		
<i>Ammotragus lervia</i>	Aoudad.....	12
<i>Anoa depressicornis</i>	Anoa.....	1
<i>Anoa quarelsii</i>	Mountain anoa.....	1
<i>Bibos gaurus</i>	Gaur.....	3
<i>Bison bison</i>	{ American bison.....	15
	{ Albino bison.....	1
<i>Bos indicus</i>	Zebu.....	6
<i>Bos taurus</i>	Texas longhorn steer.....	1
<i>Bos taurus</i>	West Highland or Kyloe cattle.....	2
<i>Bos taurus</i>	British Park cattle.....	4
<i>Bubalus bubalis</i>	Indian buffalo.....	1
<i>Cephalophus maxwellii</i>	Maxwell's duiker.....	1

ARTIODACTYLA—continued

Scientific name	Common name	Number
Bovidae—Continued.		
<i>Cephalophus niger</i>	Black duiker.....	1
<i>Cephalophus nigrifrons</i>	Black-fronted duiker.....	2
<i>Connochaetes gnou</i>	White-tailed gnu.....	1
<i>Hemitragus jemlahicus</i>	Tahr.....	8
<i>Oreotragus oreotragus</i>	Klipspringer.....	1
<i>Oryx beisa annectens</i>	Ibean beisa oryx.....	2
<i>Ovis aries</i>	Woolless or Barbados sheep.....	3
<i>Ovis europæus</i>	Mouflon.....	2
<i>Poephagus grunniens</i>	Yak.....	5
<i>Pseudos nayaur</i>	Bharal or blue sheep.....	3
<i>Synceros caffer</i>	African buffalo.....	2
<i>Taurotragus oryx</i>	Eland.....	3
Cervidae:		
<i>Axis axis</i>	Axis deer.....	4
<i>Cervus canadensis</i>	American elk.....	5
<i>Cervus elaphus</i>	Red deer.....	6
<i>Dama dama</i>	Fallow deer.....	14
	White fallow deer.....	12
<i>Muntiacus muntjak</i>	Rib-faced or barking deer.....	1
<i>Odocoileus virginianus</i>	Virginia deer.....	2
<i>Sika nippon</i>	Japanese deer.....	4
Giraffidae:		
<i>Giraffa camelopardalis</i>	Nubian giraffe.....	4
<i>Giraffa reticulata</i>	Reticulated giraffe.....	1
Camelidae:		
<i>Camelus bactrianus</i>	Bactrian camel.....	4
<i>Camelus dromedarius</i>	Single-humped camel.....	1
<i>Lama glama</i>	Llama.....	3
<i>Lama glama guanicoe</i>	Guanaco.....	2
<i>Lama pacos</i>	Alpaca.....	2
<i>Vicugna vicugna</i>	Vienna.....	2
Tayassuidæ:		
<i>Pecari angulatus</i>	Collared peccary.....	2
<i>Tayassu pecari</i>	White-lipped peccary.....	1
Suidæ:		
<i>Babirusa babirusa</i>	Babirusa.....	2
<i>Phacochoerus æthiopicus aellani</i>	East African wart hog.....	3
<i>Sus scrofa</i>	European wild boar.....	1
Hippopotamidæ:		
<i>Choeropsis liberiensis</i>	Pigmy hippopotamus.....	5
<i>Hippopotamus amphibius</i>	Hippopotamus.....	2

PERISSODACTYLA

Equidæ:		
<i>Equus burchellii antiquorum</i>	Chapman's zebra.....	4
<i>Equus grevyi</i>	Grevy's zebra.....	1
<i>Equus grevyi x asinus</i>	Zebra-ass hybrid.....	1
<i>Equus grevyi x caballus</i>	Zebra-horse hybrid.....	1
<i>Equus kiang</i>	Asiatic wild ass or kiang.....	2
<i>Equus przewalskii</i>	Mongolian wild horse.....	3
<i>Equus zebra</i>	Mountain zebra.....	1

PERISSODACTYLA—continued

Scientific name	Common name	Number
Tapiridae:		
<i>Acrocodia indica</i>	Asiatic tapir.....	2
<i>Tapirus terrestris</i>	South American tapir.....	3
Rhinocerotidae:		
<i>Rhinoceros unicornis</i>	Great Indian one-horned rhinoceros.....	1

PROBOSCIDEA

Elephantidae:		
<i>Elaphas maximus sumatranus</i>	Sumatran elephant.....	1
<i>Loxodonta africana oxyotis</i>	African elephant.....	1

HYRACOIDEA

<i>Procavia capensis</i>	Hyrax.....	2
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EDENTATA

Choloepodidae:		
<i>Choloepus didactylus</i>	Two-toed sloth.....	2
Dasypodidae:		
<i>Chaetophractus villosus</i>	Hairy armadillo.....	1
<i>Euphractus sexcinctus</i>	Six-banded armadillo.....	1

BIRDS

CASUARIIFORMES

Casuariidae:		
<i>Casuarus bennetti papuana</i>	Papuan cassowary.....	1
<i>Casuarus casuarus aruensis</i>	Aru cassowary.....	1
<i>Casuarus uniappendiculatus occipitalis</i>	Island cassowary.....	1
<i>Casuarus uniappendiculatus uniappendiculatus</i>	One-wattled cassowary.....	1
Dromicidae:		
<i>Dromicetus novaehollandiae</i>	Common emu.....	2

SPHENISCIFORMES

Spheniscidae:		
<i>Aptenodytes forsteri</i>	Emperor penguin.....	3
<i>Spheniscus demersus</i>	Jackass penguin.....	4
<i>Spheniscus humboldti</i>	Humboldt penguin.....	2

TINAMIFORMES

Tinamidae:		
<i>Eudromia elegans</i>	Crested tinamon or martineta.....	2

PELECANIFORMES

Pelecanidae:		
<i>Pelecanus californicus</i>	California brown pelican.....	4
<i>Pelecanus conspicillatus</i>	Australian pelican.....	2
<i>Pelecanus erythrorhynchos</i>	White pelican.....	4
<i>Pelecanus occidentalis</i>	Brown pelican.....	3
<i>Pelecanus onocrotalus</i>	European pelican.....	2

PELECANIFORMES—continued

Scientific name	Common name	Number
Sulidae:		
<i>Morus bassana</i>	Gannet	1
Phalacrocoracidae:		
<i>Phalacrocorax auritus albocollatus</i>	Paraliam cormorant	1
Anhingaidae:		
<i>Anhinga anhinga</i>	Anhinga	3
Fregatidae:		
<i>Fregata ariel</i>	Lesser frigate bird	1

CICONIIFORMES

Ardidae:		
<i>Ardea herodias</i>	Great blue heron	2
<i>Ardea occidentalis</i>	Great white heron	1
<i>Egretta thula</i>	Snowy egret	5
<i>Florida cacaulea</i>	Little blue heron	14
<i>Hydranassa tricolor ruficollis</i>	Louisiana heron	14
<i>Natophox novaeollandiae</i>	White-faced heron	1
<i>Nycticorax nycticorax naevius</i>	Black-crowned night heron	30
Cochleariidae:		
<i>Cochlearius cochlearius</i>	Boatbill heron	2
Ciconiidae:		
<i>Diasoura episcopus</i>	Woolly-necked stork	1
<i>Ibis cinereus</i>	Malay stork	2
<i>Leptoptilus crumeniferus</i>	Marabou	1
<i>Leptoptilus dubius</i>	Indian adjutant	1
<i>Leptoptilus javanicus</i>	Lesser adjutant	2
<i>Mycteria americana</i>	Wood ibis	1
Threskiornithidae:		
<i>Guara alba</i>	White ibis	8
<i>Guara alba</i> × <i>G. rubra</i>	Hybrid white and scarlet ibis	1
<i>Guara rubra</i>	Scarlet ibis	1
<i>Threskiornis aethiopica</i>	Sacred ibis	1
<i>Threskiornis melanocephala</i>	Black-headed ibis	4
<i>Threskiornis spinicollis</i>	Straw-necked ibis	2
Phoenicopteridae:		
<i>Phoenicopeterus chilensis</i>	Chilean flamingo	2
<i>Phoenicopeterus rubra</i>	Cuban flamingo	3

ANSERIFORMES

Anhimidae:		
<i>Chauna cristata</i>	Crested screamer	7
Anatidae:		
<i>Aiz sponsa</i>	Wood duck	7
<i>Alopochen aegyptiaca</i>	Egyptian goose	1
<i>Anas brasiliensis</i>	Brazilian teal	2
<i>Anas domestica</i>	Peking duck	12
<i>Anas platyrhynchos</i>	Mallard duck	50
<i>Anas rubripes</i>	Black duck	6
<i>Anser albifrons</i>	American white-fronted goose	3
<i>Anser cinereus domestica</i>	Toulouse goose	3
<i>Anseranas semipalmata</i>	Australian plied goose	2

ANSERIFORMES—continued

Scientific name	Common name	Number
Anatidae—Continued.		
<i>Branta canadensis</i>	Canada goose	25
<i>Branta canadensis hutchinsii</i>	Hutchin's goose	4
<i>Branta canadensis minima</i>	Cackling goose	8
<i>Branta canadensis occidentalis</i>	White-cheeked goose	25
<i>Cairina moschata</i>	Muscovy duck	11
<i>Casarca variegata</i>	Paradise duck	1
<i>Cercopsis novae-hollandiae</i>	Cape Barren goose	2
<i>Chen atlantica</i>	Snow goose	3
<i>Chen caerulescens</i>	Blue goose	2
<i>Chenopsis atrata</i>	Black swan	4
<i>Chloephaga leucoptera</i>	Magellan goose	2
<i>Cygnopsis cygnoides</i>	Domestic goose	2
<i>Cygnus columbianus</i>	Whistling swan	2
<i>Cygnus melancoriphus</i>	Black-necked swan	1
<i>Cygnus olor</i>	Mute swan	5
<i>Dafila acuta</i>	Pintail	8
<i>Dafila spinicauda</i>	Chilean pintail	1
<i>Dendrocygna arborea</i>	Black-billed tree duck	3
<i>Dendrocygna autumnalis</i>	Black-bellied tree duck	2
<i>Dendrocygna viduata</i>	White-faced tree duck	4
<i>Dendrocygna galericulata</i>	Mandarin duck	4
<i>Mareca americana</i>	Baldpate	1
<i>Marila affinis</i>	Lesser scaup	1
<i>Marila collaris</i>	Ring-necked duck	1
<i>Neochen jubata</i>	Orinoco goose	2
<i>Nettion carolinense</i>	Green-winged teal	1
<i>Nettion formosum</i>	Baikol teal	5
<i>Nyroca</i> sp.	Hybrid duck	1
<i>Nyroca vatisinoria</i>	Canvasback duck	1
<i>Phalacrocorax carolinensis</i>	Emperor goose	3
<i>Querquedula discors</i>	Blue-winged teal	8
Cathartidae:		
<i>Cathartes aura</i>	Turkey vulture	2
<i>Coragyps atratus</i>	Black vulture	1
<i>Gymnogyps californianus</i>	California condor	1
<i>Gypohierax angolensis</i>	Fish-eating vulture	1
<i>Gyps ruppelli</i>	Ruppell's vulture	1
<i>Sarcoramphus papa</i>	King vulture	1
<i>Torgos tracheliotus</i>	African eared vulture	1
Accipitridae:		
<i>Accipiter cooperi</i>	Cooper's hawk	1
<i>Buteo borealis</i>	Red-tailed hawk	8
<i>Buteo lineatus elegans</i>	Southern red-shouldered hawk	1
<i>Buteo lineatus lineatus</i>	Red-shouldered hawk	2
<i>Buteo melanoleucus</i>	South American buzzard eagle	2
<i>Buteo platypterus</i>	Broad-winged hawk	1
<i>Buteo poecilochrous</i>	Red-backed buzzard	1

ANSERIFORMES—continued

Scientific name	Common name	Number
Accipitridae—Continued.		
<i>Haliaeetus leucocephalus</i>	Bald eagle.....	6
<i>Haliaeetus indus</i>	Brahminy kite.....	5
<i>Harpia harpya</i>	Harpy eagle.....	2
<i>Hypomorphnus urubitinga</i>	Brazilian eagle.....	1
<i>Milvago chimango</i>	Chimango.....	3
<i>Milvus migrans parasitus</i>	African yellow-billed kite.....	2
<i>Pandion haliaeetus carolinensis</i>	Osprey or fish hawk.....	1
<i>Parabuteo unicinctus</i>	One-banded hawk.....	1
Falconidae:		
<i>Cerchneis sparverius</i>	Sparrow hawk.....	5
<i>Daptrius americanus</i>	Red-throated caracara.....	3
<i>Falco peregrinus anatum</i>	Duck hawk.....	1
<i>Polyborus plancus</i>	South American caracara.....	1

GALLIFORMES

Cracidae:		
<i>Crax fasciolata</i>	Crested curassow.....	2
<i>Crax rubra</i>	Panama curassow.....	1
<i>Crax sclateri</i>	Sclater's curassow.....	1
<i>Mitu mitu</i>	Razor-billed curassow.....	2
Phasianidae		
<i>Argusianus argus</i>	Argus pheasant.....	2
<i>Catreus wallichii</i>	Cheer pheasant.....	3
<i>Chrysolophus amherstiae</i>	Lady Amherst's pheasant.....	1
<i>Chrysolophus pictus</i>	Golden pheasant.....	5
<i>Colinus cristatus</i>	Crested quail.....	2
<i>Colinus virginianus</i>	Bobwhite.....	1
<i>Gallus gallus</i>	Red jungle fowl.....	4
<i>Gallus lafayetti</i>	Ceylonese jungle fowl.....	1
<i>Gallus sp.</i>	Bantam chicken.....	1
<i>Gallus sp.</i>	Fighting fowl.....	1
<i>Gallus sp.</i>	Long-tailed fowl.....	1
<i>Gennaeus albocristatus</i>	White-crowned kaleege.....	3
<i>Gennaeus nyctomerus</i>	Silver pheasant.....	6
<i>Hierophasis swinhoei</i>	Swinhoe's pheasant.....	2
<i>Lophophorus impeyanus</i>	Himalayan Impeyan pheasant.....	1
<i>Lophortyx californica callicola</i>	Valley quail.....	2
<i>Pavo cristatus</i>	Peafowl.....	4
<i>Phasianus torquatus</i>	Ring-necked pheasant.....	6
	White ring-necked pheasant.....	3
	Melanistic mutant ring-necked pheasant.....	3
<i>Phasianus versicolor</i>	Green Japanese pheasant.....	1
<i>Polyplectron napoleonis</i>	Palawan peacock pheasant.....	1
<i>Symaticus reevesi</i>	Reeves' pheasant.....	2
Numididae:		
<i>Acryptium vulturinum</i>	Vulturine guinea fowl.....	1
<i>Numida sp.</i>	Guinea fowl.....	2

GRUTIFORMES

Scientific name	Common name	Number
Rhinocetidae:		
<i>Rhinoceros jubatus</i>	Kagu.....	1
Gruidae:		
<i>Anthropoides paradisea</i>	Stanley or Paradise crane.....	3
<i>Anthropoides virgo</i>	Demoiselle crane.....	5
<i>Balearica pavonina</i>	West African crowned crane.....	3
<i>Balearica regulorum gibbericeps</i>	East African crowned crane.....	1
<i>Grus canadensis canadensis</i>	Little brown crane.....	1
<i>Grus leucauchen</i>	White-naped crane.....	1
<i>Grus leucogeranus</i>	Siberian crane.....	2
Rallidae:		
<i>Amayornis phoenicurus</i>	White-breasted rail.....	2
<i>Fulica americana</i>	American coot.....	6
<i>Gallinula chloropus cachinnans</i>	Florida gallinule.....	2
<i>Gallinula chloropus orientalis</i>	Sumatran gallinule.....	2
<i>Limnecorax fascirostra</i>	African black rail.....	3
<i>Porphyrio poliocephalus</i>	Gray-headed porphyrio.....	2
Carlamidae:		
<i>Carlama cristata</i>	Carlama or seriama.....	2

CHARADRIIFORMES

Haematopodidae:		
<i>Haematopus ostralegus</i>	European oyster catcher.....	2
Charadriidae:		
<i>Belanopterus chilensis</i>	Chilean lapwing.....	2
Laridae:		
<i>Larus argentatus</i>	Herring gull.....	1
<i>Larus delawarensis</i>	Ring-billed gull.....	1
<i>Larus dominicanus</i>	Kelp gull.....	2
<i>Larus glaucescens</i>	Glaucous-winged gull.....	1
<i>Larus novaehollandiae</i>	Silver gull.....	15
Glariolidae:		
<i>Glareola pratincola</i>	Collared pratincole.....	1

COLUMBIFORMES

Columbidae:		
<i>Columba guinea</i>	Triangular-spotted pigeon.....	1
<i>Columba livia</i>	Domestic pigeon.....	3
<i>Columba maculosa</i>	Spot-winged pigeon.....	1
<i>Ducula aenea</i>	Green imperial pigeon.....	1
<i>Gallinocolumba luzonica</i>	Bleeding-heart dove.....	4
<i>Goura cristata</i>	Sclater's crowned pigeon.....	1
<i>Goura victoria</i>	Victoria crowned pigeon.....	1
<i>Leptotilia cassini</i>	Cassin's dove.....	1
<i>Muscadivores paulina</i>	Celebian imperial pigeon.....	1
<i>Streptopelia chinensis</i>	Asiatic collared dove.....	1
<i>Streptopelia chinensis ceylonensis</i>	Lace-necked or ash dove.....	3
<i>Streptopelia tranquebarica</i>	Blue-headed ring dove.....	2
<i>Turtur risorius</i>	Ring-necked dove.....	12
<i>Zenaida auriculata</i>	South American mourning dove.....	5
<i>Zenaidura macroura</i>	Mourning dove.....	1

PSITTACIFORMES

Scientific name	Common name	Number
Psittacidae:		
<i>Agapornis pullaria</i>	Red-faced lovebird.....	3
<i>Amazona auropalliata</i>	Yellow-naped parrot.....	4
<i>Amazona ochrocephala</i>	Yellow-headed parrot.....	1
<i>Amazona oratrix</i>	Double yellow-headed parrot.....	2
<i>Anodorhynchus hyacinthinus</i>	Hyacinthine macaw.....	1
<i>Ara ararauna</i>	Yellow and blue macaw.....	2
<i>Ara macao</i>	Red, blue, and yellow macaw.....	2
<i>Ara militaria</i>	Mexican green macaw.....	1
<i>Aratinga euops</i>	Cuban conure.....	2
<i>Calyptorhynchus magnificus</i>	Banksian cockatoo.....	1
<i>Coracopsis nigra</i>	Lesser vasa parrot.....	1
<i>Cyanopsittacus spixi</i>	Spix's macaw.....	1
<i>Eucorpeis sanguineus</i>	Bare-eyed cockatoo.....	1
<i>Eclectus pectoralis</i>	Eclectus parrot.....	1
<i>Eolophus roseicapillus</i>	Roseate cockatoo.....	3
<i>Kakatoe alba</i>	White cockatoo.....	2
<i>Kakatoe galerita</i>	Large sulphur-crested cockatoo.....	2
<i>Kakatoe leadbeateri</i>	Leadbeater's cockatoo.....	1
<i>Kakatoe moluccensis</i>	Great red-crested cockatoo.....	5
<i>Kakatoe sulphurea</i>	Lesser sulphur-crested cockatoo.....	2
<i>Lorius domicella</i>	Rajah lory.....	1
<i>Lorius parrulus</i>	Red lory.....	1
<i>Metopsittacus undulatus</i>	Grass paroquet.....	12
<i>Myopsitta monachus</i>	Quaker paroquet.....	1
<i>Nandayus nanday</i>	Nanday paroquet.....	1
<i>Nectar notabilis</i>	Kea.....	1
<i>Nymphicus hollandicus</i>	Cockatiel.....	1
<i>Pionites xanthomeria</i>	Amazonian calique.....	2
<i>Psittacula eupatria</i>	Red-shouldered paroquet.....	3
<i>Psittacula krameri</i>	Kramer's paroquet.....	2
<i>Psittacula longicauda</i>	Long-tailed paroquet.....	2
<i>Tanygnathus muelleri</i>	Mueller's parrot.....	1

CUCULIFORMES

Cuculidae:		
<i>Eudynamis scolopaceus</i>	Koel.....	1
Musophagidae:		
<i>Turacus livingstoni</i>	Livingston's turacou.....	1

STRIGIFORMES

Tytonidae:		
<i>Tyto alba pratincola</i>	Barn owl.....	3
Strigidae:		
<i>Bubo virginianus</i>	Great horned owl.....	7
<i>Ketupa ketupu</i>	Malay fish owl.....	1
<i>Nyctea nyctea</i>	Snowy owl.....	1
<i>Otus asio</i>	Screech owl.....	3
<i>Strix varia varia</i>	Barred owl.....	4

CAPRIMULGIFORMES

Scientific name	Common name	Number
Podargidae:		
<i>Podargus strigoides</i>	Tawny frogmouth.....	1

COLLIFORMES

Collidae:		
<i>Colius striatus</i>	Streaked mouse bird or coly.....	2

CORACIFORMES

Alcedinidae:		
<i>Dacelo pigas</i>	Kookaburra.....	2
<i>Halcyon sanctus</i>	Sacred kingfisher.....	1
Momotidae:		
<i>Momotus lessoni</i>	Motmot.....	1

PICIFORMES

Ramphastidae:		
<i>Aulacorhynchus sulcatus sulcatus</i>	Groove-billed toucanet.....	1
<i>Pteroglossus aracari</i>	Black-necked aracari.....	2
<i>Ramphastos carinatus</i>	Sulphur-breasted toucan.....	7
<i>Ramphastos culminatus</i>	White-breasted toucan.....	1
<i>Ramphastos piscivorus</i>	Toco toucan.....	1

PASSERIFORMES

Cotingidae:		
<i>Melanotis caerulescens</i>	Mexican catbird.....	2
<i>Rupicola peruviana sanguinolenta</i>	Scarlet cock-of-the-rock.....	2
Corvidae:		
<i>Callocitta formosa</i>	Mexican jay.....	1
<i>Cissa chinensis</i>	Chinese cissa.....	2
<i>Oxylipha yucatanica</i>	Yucatan blue jay.....	4
<i>Corvus albus</i>	White-breasted crow.....	2
<i>Corvus brachyrhynchos</i>	American crow.....	7
<i>Corvus corax principalis</i>	Northern raven.....	3
<i>Corvus cornix</i>	Hooded crow.....	2
<i>Corvus cryptoleucus</i>	White-necked raven.....	1
<i>Corvus insolens</i>	Indian crow.....	3
<i>Cyanocorax chrysops</i>	Uracca jay.....	1
<i>Cyanocorax mystacalis</i>	Moustached jay.....	1
<i>Cyanopici cyana</i>	Azure-winged pie.....	1
<i>Gymnorhina hypoleuca</i>	White-backed piping crow.....	2
<i>Urocissa caerulea</i>	Formosan red-billed pie.....	2
<i>Urocissa occipitalis</i>	Red-billed blue magpie.....	1
Paradiseldae:		
<i>Ailuroedus crassirostris</i>	Australian catbird.....	1
<i>Epimachus fastuosus</i>	Sickle-billed bird of paradise.....	1
<i>Ptilonorhynchus violaceus</i>	Satin bowerbird.....	1
<i>Selenicida niger</i>	12-wired bird of paradise.....	1
Pycnonotidae:		
<i>Pycnonotus analis</i>	Yellow-vented bulbul.....	1
Irenidae:		
<i>Irena puella</i>	Fairy blue bird.....	1

PASSERIFORMES—continued

Scientific name	Common name	Number
Mimidae:		
<i>Melanotis caerulescens</i>	Blue mockingbird.....	1
<i>Toxostoma rufum</i>	Brown thrasher.....	1
Turdidae:		
<i>Garrulax pectoralis picticollis</i>	Chinese collared laughing thrush.....	1
<i>Garrulax perspicillatus</i>	Spectacled laughing thrush.....	1
<i>Leiothrix luteus</i>	Pekin robin.....	2
<i>Turdus grayi</i>	Bonaparte's thrush.....	1
<i>Turdus rufoventris</i>	Argentine robin.....	3
Sturnidae:		
<i>Cosmopsarus regius</i>	Splendid starling.....	1
<i>Creatophora cinerea</i>	Wattled starling.....	1
<i>Galeopsar salvadorii</i>	Crested starling.....	1
<i>Graculipica melanoptera</i>	White starling.....	1
Ploceidae:		
<i>Diatropura procne</i>	Giant whydah.....	4
<i>Lonchura leucogastroidea</i>	Bengalee.....	5
<i>Munia maja</i>	White-headed munia.....	2
<i>Munia malacca</i>	Black-throated munia.....	1
<i>Munia oryzivora</i>	Java sparrow.....	7
<i>Munia punctulatus</i>	Rice bird or nutmeg finch.....	2
<i>Ploceus baya</i>	Baya weaver.....	3
<i>Ploceus intermedius</i>	Black-cheeked weaver.....	5
<i>Ploceus rubiginosus</i>	Chestnut-breasted weaver.....	1
<i>Poephila acuticauda</i>	Long-tailed finch.....	1
<i>Poephila gouldiae</i>	Gouldian finch.....	2
<i>Quelea sanguinirostris intermedia</i>	Southern masked weaver finch.....	2
<i>Steganura paradisea</i>	Paradise whydah.....	5
<i>Taeniopygia castanotis</i>	Zebra finch.....	3
	White zebra finch.....	1
Coerebidae:		
<i>Cyanerpes cyaneus</i>	Blue honeycreeper.....	6
Icteridae:		
<i>Agelaius assimilis</i>	Cuban red-winged blackbird.....	2
<i>Cassidix melanicterus</i>	Mexican cacique.....	1
<i>Gymnomystax mexicanus</i>	Giant oriole.....	1
<i>Icterus bullocki</i>	Bullock's troupial.....	2
<i>Icterus icterus</i>	Troupial.....	1
<i>Molothrus bonariensis</i>	Shiny cowbird.....	1
<i>Notiopsar curaeus</i>	Chilean blackbird.....	2
<i>Trupialis desfilippi</i>	Military starling.....	8
Thraupidae:		
<i>Piranga bidentata</i>	Orange tanager.....	1
<i>Ramphocelus dimidiatus</i>	Crimson tanager.....	1
<i>Ramphocelus flamigerus</i>	Yellow tanager.....	4
<i>Ramphocelus icteronotus</i>	Yellow-rumped tanager.....	2
<i>Thraupis episcopus</i>	Blue tanager.....	2
Fringillidae:		
<i>Amandava amandava</i>	Strawberry finch.....	10
<i>Carduelis carduelis</i>	European gold finch.....	1

PASSEIRIFORMES—continued

Scientific name	Common name	Number
Fringillidae—Continued.		
<i>Carpodacus mexicanus</i>	Mexican house finch.....	4
<i>Coryphospingus cucullatus</i>	Red-crested finch.....	2
<i>Cyanocampsa argentina</i>	Argentine blue grosbeak.....	2
<i>Diuca diuca</i>	Diuca finch.....	2
<i>Erythrura psittacea</i>	New Caledonian parrot finch.....	1
<i>Lophospingus pusillus</i>	Black-crested finch.....	3
<i>Melopyrrha nigra</i>	Cuban bullfinch.....	1
<i>Porcaria cucullata</i>	Brazilian cardinal.....	3
<i>Passerina cyanea</i>	Indigo bunting.....	2
<i>Passerina leclancherii</i>	Leclancher's bunting.....	6
<i>Passerina versicolor</i>	Blue bunting.....	2
<i>Phrygilus fruticeti</i>	Mourning finch.....	8
<i>Phrygilus gayi</i>	Gay's gray-headed finch.....	4
<i>Serinus canarius</i>	Canary.....	4
<i>Sicalis flaveola</i>	Mysto finch.....	1
<i>Sicalis luteola</i>	Saffron finch.....	3
<i>Sicalis minor</i>	Lesser yellow finch.....	4
<i>Spinus uropygialis</i>	Chilean siskin.....	3
<i>Sporophila urula</i>	Hick's seed-eater.....	2
<i>Sporophila gutturalis</i>	Yellow-bellied seed-eater.....	2
<i>Tiaris olivacea</i>	Mexican grassquit.....	1
<i>Volatinia jacarini</i>	Blue-black grassquit.....	1
<i>Zonotrichia capensis</i>	Chingolo.....	2

REPTILES

LOBICATA

Crocodylidae:

<i>Alligator mississippiensis</i>	Alligator.....	22
<i>Alligator sinensis</i>	Chinese alligator.....	3
<i>Caiman latirostris</i>	Broad-snouted caiman.....	1
<i>Caiman sclerops</i>	Spectacled caiman.....	3
<i>Crocodylus acutus</i>	American crocodile.....	4
<i>Crocodylus entaphractus</i>	Narrow-nosed crocodile.....	1
<i>Crocodylus niloticus</i>	African crocodile.....	2
<i>Crocodylus palustris</i>	"Toad" crocodile.....	2
<i>Crocodylus porosus</i>	Salt-water crocodile.....	1
<i>Crocodylus rhombifer</i>	Cuban crocodile.....	1
<i>Osteolaemus tetraspis</i>	Broad-nosed crocodile.....	2

SAURIA

Gekkonidae:

<i>Gekko gekko</i>	Gecko.....	2
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Iguanidae:

<i>Anolis carolinensis</i>	False "chameleon".....	20
<i>Basiliscus sp.</i>	Banded basilisk.....	4
<i>Ctenosaura acanthura</i>	Spiny-tailed iguana.....	2
<i>Phrynosoma cornutum</i>	Horned lizard.....	17
<i>Sceloporus undulatus</i>	Pine or fence lizard.....	8

SAURIA—continued

Scientific name	Common name	Number
Anguidae:		
<i>Ophisaurus apus</i>	European glass snake.....	1
<i>Ophisaurus ventralis</i>	Glass snake or legless lizard.....	6
<i>Gerrhonotus coeruleus principis</i>	Alligator lizard.....	2
Helodermatidae:		
<i>Heloderma horridum</i>	Mexican beaded lizard.....	2
<i>Heloderma suspectum</i>	Gila monster.....	7
Tellidae:		
<i>Onemidophorus sexlineatus</i>	Six-lined race runner.....	5
<i>Crocodylurus lacertinus</i>	Crocodile lizard.....	1
<i>Tupinambis nigropunctatus</i>	Black tegu.....	1
Scincidae:		
<i>Egernia cunninghami</i>	Cunningham's skink.....	2
<i>Eumeces fasciatus</i>	Blue-tailed skink.....	3
<i>Tiliqua scincoides</i>	Blue-tongued lizard.....	2
Varanidae:		
<i>Varanus komodoensis</i>	Komodo dragon.....	1
<i>Varanus monitor</i>	Indian monitor.....	2
<i>Varanus niloticus</i>	Nile monitor.....	3
<i>Varanus salvator</i>	Sumatran monitor.....	5

OPHIDIA

Boidae:		
<i>Boa conkii</i>	Cook's tree boa.....	1
<i>Charina bottae</i>	Rubber boa.....	1
<i>Constrictor constrictor</i>	Bon constrictor.....	3
<i>Constrictor imperator</i>	Central America boa.....	2
<i>Epiplatys cenchris</i>	Rainbow boa.....	6
<i>Epiplatys crassus</i>	Salamanca.....	1
<i>Epiplatys striatus</i>	Haitian boa.....	1
<i>Eumeces murinus</i>	Anaconda.....	1
<i>Lichanura roseofusca</i>	California rosy boa.....	1
<i>Python molurus</i>	Indian rock python.....	9
<i>Python regius</i>	Ball python.....	3
<i>Python reticulatus</i>	Regal python.....	3
<i>Python variegatus</i>	Carpet python.....	1
<i>Tropidophis melanurus</i>	Cuban boa.....	1
Colubridae:		
<i>Carphophis amoenus</i>	Worm snake.....	1
<i>Coluber constrictor</i>	Black snake.....	1
<i>Cyclagras gigas</i>	Cobra de Paraguay.....	1
<i>Diadophis punctatus</i>	Ring-necked snake.....	1
<i>Drymarchon corais couperi</i>	Indigo snake.....	2
<i>Elaphe guttata</i>	Corn snake.....	3
<i>Elaphe obsoleta</i>	Pilot snake.....	6
<i>Elaphe quadrivittata</i>	Yellow chicken snake.....	1
<i>Heterodon contortrix</i>	Hog-nosed snake.....	4
<i>Lampropeltis getulus floridana</i>	Florida king snake.....	1
<i>Lampropeltis getulus getulus</i>	Chain or king snake.....	1
<i>Natrix piscator</i>	Water snake.....	15

OPHIDIA—continued

Scientific name	Common name	Number
Colubridae—Continued.		
<i>Natrix septemvittata</i>	Queen or moon snake.....	3
<i>Natrix</i> sp.....	Water snake.....	1
<i>Pituophis catenifer</i>	Western bull snake.....	2
<i>Pituophis catenifer annectans</i>	San Diego gopher snake.....	2
<i>Pituophis melanoleucus</i>	Bull snake.....	1
<i>Ptyas mucosus</i>	Rat snake.....	1
<i>Rhinocheilus lecontei</i>	Long-nosed snake.....	1
<i>Storeria dekayi</i>	De Kay's snake.....	1
<i>Thamnophis ordinoides</i>	Western garter snake.....	26
<i>Thamnophis sirtalis</i>	Garter snake.....	4
Elapidae:		
<i>Naja naja</i>	Indian cobra.....	1
<i>Oxybelis fulgidus</i>	Green tree snake.....	1
Crotalidae:		
<i>Agkistrodon mokeson</i>	Copperhead snake.....	4
<i>Agkistrodon piscivorus</i>	Water moccasin.....	1
<i>Crotalus adamanteus</i>	Florida diamond-backed rattlesnake.....	1
<i>Vipera russelli</i>	Russell's viper.....	1

TESTUDINATA

Chelydridae:		
<i>Batrachemys nasuta</i>	South American side-necked turtle.....	1
<i>Chelodina longicollis</i>	Australian snake-necked turtle.....	1
<i>Hydaspis</i> sp.....	South American snake-necked turtle.....	3
<i>Hydromedusa tectifera</i>	Snake-necked turtle.....	16
<i>Platemys platycephala</i>	Flat-headed turtle.....	1
Platysternidae:		
<i>Platysternum megacephalum</i>	Large-headed Chinese turtle.....	1
Pelomedusidae:		
<i>Pelomedusa galeata</i>	Common African water tortoise.....	2
<i>Podocnemis expansa</i>	South American river tortoise.....	1
Kinosternidae:		
<i>Kinosternon</i> sp.....	Central American musk turtle.....	1
<i>Kinosternon subrubrum</i>	Musk turtle.....	4
Chelydridae:		
<i>Chelydra serpentina</i>	Snapping turtle.....	8
<i>Macrochelys temminckii</i>	Alligator snapping turtle.....	1
Testudinidae:		
<i>Chrysemys marginata</i>	Western painted turtle.....	5
<i>Chrysemys picta</i>	Painted turtle.....	3
<i>Clemmys guttata</i>	Spotted turtle.....	6
<i>Clemmys insculpta</i>	Wood turtle.....	7
<i>Clemmys mühlenbergii</i>	Mühlenberg's tortoise.....	1
<i>Cyclemys amboinensis</i>	Kura kura box turtle.....	4
<i>Emys blandingii</i>	Blanding's turtle.....	1
<i>Geoclemys subtrijuga</i>	Siamese field turtle.....	1
<i>Graptemys barbouri</i>	Barbour's turtle.....	7
<i>Graptemys pseudogeographica</i>	False map turtle.....	1

TESTUDINATA—continued

Scientific name	Common name	Number
Testudinidae—continued.		
<i>Kinixys erosa</i>	West African back-hinged tortoise.....	1
<i>Malaclemys centrata</i>	Diamond-back turtle.....	24
<i>Pseudemys concinna</i>	Cooter.....	3
<i>Pseudemys elegans</i>	Cumberland terrapin.....	2
<i>Pseudemys ornata</i>	Central American water turtle.....	1
<i>Pseudemys rugosa</i>	Cuban terrapin.....	1
<i>Terrapene carolina</i>	Box turtle.....	50
<i>Terrapene major</i>	Florida box turtle.....	4
<i>Terrapene sp</i>	Mexican box turtle.....	2
<i>Testudo chilensis</i>	Chilean land tortoise.....	1
<i>Testudo denticulata</i>	South American land tortoise.....	2
<i>Testudo elegans</i>	Star tortoise.....	2
<i>Testudo ephippium</i>	Duncan Island tortoise.....	1
<i>Testudo hoodensis</i>	Hood Island tortoise.....	3
<i>Testudo tornieri</i>	Soft-shelled land tortoise.....	2
<i>Testudo vicina</i>	Albemarle Island tortoise.....	3
Trionychidae:		
<i>Amyda ferox</i>	Soft-shelled turtle.....	6
<i>Amyda triunguis</i>	West African soft-shelled turtle.....	1

AMPHIBIA

CAUDATA

Salamandridae:		
<i>Trifurcus pyrrhogaster</i>	Red salamander.....	3
<i>Triturus torosus</i>	Giant newt.....	16
<i>Triturus viridescens</i>	Common newt.....	4
Amphiumidae:		
<i>Amphiuma means</i>	Blind eel or Congo snake.....	1
Cryptobranchidae:		
<i>Cryptobranchus alleganiensis</i>	Hellbender.....	4
Necturidae:		
<i>Necturus maculosus</i>	Mudpuppy.....	1

SALIENTIA

Dendrobatidae:		
<i>Dendrobates auratus</i>	Arrow-poison frog.....	3
Bufonidae:		
<i>Bufo americanus</i>	Common toad.....	25
<i>Bufo emplusus</i>	Sapo de concha.....	8
<i>Bufo marinus</i>	Marine toad.....	6
<i>Bufo peltoccephalus</i>	Cuban giant toad.....	3
Ceratophryidae:		
<i>Ceratophrys ornata</i>	Horned frog.....	5
Hylidae:		
<i>Acris gryllus</i>	Crickit frog.....	20
<i>Hyla crucifer</i>	Tree frog.....	3
Pipidae:		
<i>Pipa americana</i>	Surinam toad.....	3

SALIENTIA—continued

Scientific name	Common name	Number
Ranidae:		
<i>Rana catesbeiana</i>	Bullfrog.....	3
<i>Rana clamitans</i>	Green frog.....	3
<i>Rana occipitalis</i>	West African bullfrog.....	1
<i>Rana pipiens</i>	Leopard frog.....	5
<i>Rana sylvatica</i>	Wood frog.....	3

FISHES

<i>Acanthophtalmus kuhli</i>	Banded loach.....	1
<i>Aequidens portalegrensis</i>	Blue acara.....	1
<i>Aphysemion australe</i>	Lyre-tailed fish.....	2
<i>Astronotus ocellatus</i>.....	.....	1
<i>Barbus everetti</i>	Clown barb.....	8
<i>Barbus oligolepis</i>.....	.....	3
<i>Barbus sumatranus</i>.....	.....	2
<i>Calamarichthys malabaricus</i>	West African ganoid.....	6
<i>Cichlasoma festivum</i>	Banded acara.....	10
<i>Corydoras melanistius</i>	Armored catfish.....	1
<i>Corydoras rabaulti</i>	Rabaut catfish.....	1
<i>Corydoras</i> sp.....	Catfish.....	2
<i>Epalzeorhynchus talopecterus</i>	Black-fin shark.....	1
<i>Gymnocorymbus ternetzi</i>	Black tetra.....	4
<i>Hemigrammus</i> sp.....	Tetra Buenos Aires.....	6
<i>Hyphessobrycon innesi</i>	Neon tetra fish.....	3
<i>Kryptopterus bicirrhus</i>	Glass catfish.....	3
<i>Lebistes reticulatus</i>	Guppy.....	100
<i>Lepidosiren paradoxa</i>	South American lungfish.....	3
<i>Macropodus</i> sp.....	Paradise fish.....	20
<i>Mollenisia sphenops</i>	Saltfin molly.....	10
<i>Nannostomus marginatus</i>.....	.....	2
<i>Nannostomus trilineatus</i>.....	.....	2
<i>Platypoecilus</i>	Red moon.....	50
<i>Platypoecilus maculatus</i>	Black wag-tail moon.....	30
<i>Platypoecilus maculatus</i>	Goldplaties.....	12
<i>Plecostomus</i> sp.....	Armored catfish.....	1
<i>Pristella riddlei</i>.....	.....	1
<i>Protopterus annectens</i>	African lungfish.....	2
<i>Pterophyllum scalare</i>	Angel fish.....	2
<i>Puntius partipentazona</i>	Red-flamed barb.....	8
<i>Rasbora heteromorpha</i>.....	.....	2
<i>Serrasalminus ternetzi</i>	Piranha or cannibal fish.....	1
<i>Tanichthys albanubes</i>	White Cloud Mountain fish.....	30
<i>Tilapia</i> sp.....	Month-breeding fish.....	2
<i>Trichogaster leeri</i>	Three-spot gourami.....	2
<i>Xiphophorus helleri</i>	{ Swordtail.....	15
	{ Red swordtail.....	6
	{ Tuxedo swordtail.....	12

ARACHNIDS

<i>Scientific name</i>	<i>Common name</i>	<i>Number</i>
<i>Eurypelma</i> sp.-----	Tarantula-----	2
<i>Latrodectus mactans</i> -----	Black widow spider-----	3

INSECTS

<i>Blaber</i> sp.-----	Giant cockroach-----	100
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Respectfully submitted.

W. M. MANN, *Director*.

THE SECRETARY,
Smithsonian Institution.

APPENDIX 8

REPORT ON THE ASTROPHYSICAL OBSERVATORY

Sir: I have the honor to submit the following report on the activities of the Astrophysical Observatory, including the Division of Astrophysical Research and the Division of Radiation and Organisms, for the fiscal year ended June 30, 1944:

DIVISION OF ASTROPHYSICAL RESEARCH

No male assistants could be retained at the three solar-constant observing stations, Montezuma, Chile, Table Mountain, Calif., and Tyronne, N. Mex., on account of war conditions. In this situation the wives of the three field directors, Greeley, Warner, and Moore, have stepped into the breach and are assisting with observing and computing. It has therefore been possible to keep the three stations in operation in this exceptionally interesting period.

As pointed out in last year's report, the predicted march of solar variation through 1945 indicates a large depression of solar radiation beginning in October 1944, comparable to that which occurred 23 years earlier, beginning in 1921. Figure 1 shows that the observations made at Montezuma observatory up to the middle of the year 1943 support thus far the trend of the prediction published in figure 14 of volume 6 of the *Annals of the Astrophysical Observatory*. It is therefore confidently expected that the depression of the solar constant will begin with October 1944. It is not yet possible to forecast what exact effects this depression (similar to that of 23 years ago) may produce in weather, but as stated in an article a generation ago by Abbot,¹ unusual weather conditions may be anticipated.

Most of the time of Mr. Hoover, Mrs. Bond, and Miss Simpson at Washington, and part of that of Mr. Aldrich has been occupied with the reduction and determining of the statistical corrections for the solar-constant work of the three observing stations since 1939. Additional types of observing, namely, polarization of the sky, and energy spectrum observations limited to the ultraviolet region, have accumulated in these recent years. Their bearing on the determination of the solar variation is of great interest.

Mr. Aldrich has been largely occupied with special secret war problems, and part of Dr. Abbot's time has been thus spent also.

¹ *Proc. Nat. Acad. Sci.*, vol. 9, No. 6, pp. 194-198, June 1923.

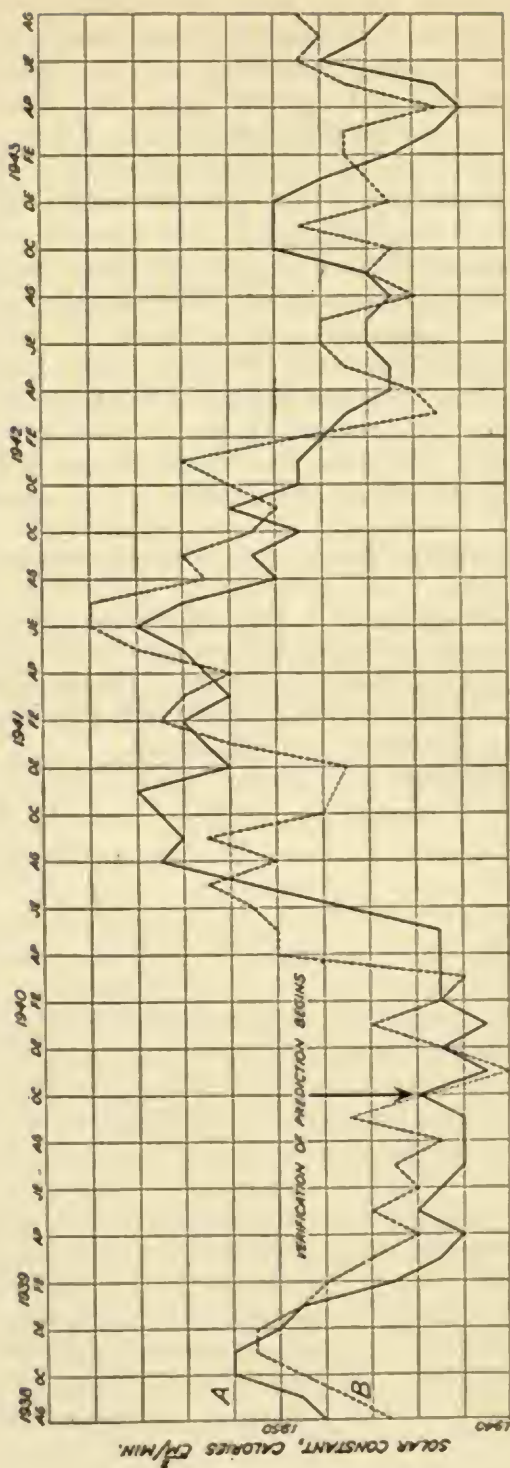


FIGURE 1.—The solar constant of radiation. A, predicted; B, observed.

A major part of Dr. Abbot's work has consisted in the study of solar-constant variation and associated solar changes in connection with the weather. A paper entitled "Weather Predetermined by Solar Variation" has resulted, and appeared just at the close of the fiscal year. In the course of these studies it was found that variations of the areas of clouds of calcium vapor (calcium flocculi) as photographed at the Spanish Observatory of Ebro since 1910 were associated in the same way as solar-constant changes in predetermining the weather. This led to an attempt to weaken the light of the sun's disk by excessive spectral dispersion so far as to make visible variations of the bright lines of hydrogen or helium in the chromosphere. Doubtful evidences of such chromospheric lines were indeed recorded, but though the dispersion of the third order of a grating of 15,000 lines to the inch, a battery of prisms, and a path of 55 meters of travel of the spectrum rays were employed, the photospheric spectrum was still too bright to disclose plainly the chromospheric lines or their variation.

DIVISION OF RADIATION AND ORGANISMS

As in the preceding year the work of this Division was mainly concerned with secret problems relating to the war. However, a paper entitled "The Influence of Light and of Carbon Dioxide on the Respiration of Etiolated Barley Seedlings" was prepared and published by Drs. Weintraub and Johnston.

Respectfully submitted,

C. G. ABBOT,
Director.

THE SECRETARY,
Smithsonian Institution.

APPENDIX 9

REPORT ON THE LIBRARY

SIR: I have the honor to submit the following report on the activities of the Smithsonian library for the fiscal year ended June 30, 1944:

From the point of view of use, the year has been an outstanding one. Never before in the history of the world have books played so significant a part in the successful waging of war. As the war goes on, the potential importance of all recorded items of human knowledge through integration with others becomes increasingly evident, and often is strikingly demonstrated. It seems a far cry from the bookstacks of a scientific library to the battlefields of Africa or the South Pacific, but this is a scientific war, and many lives have been saved by the exactly right bit of information about an insect, a plant, an animal, the shore line of a far-away island, or other natural features of strange lands found in little-known journals and documents on library shelves.

In the Smithsonian library examples of the conversion to wartime uses of the published results of peacetime scientific investigations and explorations might be multiplied almost indefinitely, for the library has been increasingly used by the war agencies and by individuals in the armed forces. In the Museum library alone, where a count of reference questions coming from these sources was kept, there were 520 requests for information, many of which required a very considerable amount of research to answer. The library of the Bureau of American Ethnology was frequently called upon, and the resources of the Astrophysical Observatory library were often in demand, especially through the loan of scientific journals to other libraries. The staff of the Ethnogeographic Board constantly searched all the branch libraries for material useful to its various projects in aid of the war agencies.

War use also accounts for the rise in the number of interlibrary loans from 687 in 1943 to 1,363 during the year just past.

The library's large collection of duplicates, too, has been drawn upon by other departments of the Government, and many publications no longer needed have been sent to fill gaps in sets in the older departmental libraries or to help build up special collections in the more recently established war agencies.

Through the Library of Congress, the Smithsonian library is co-operating with the American Library Association in its program of collecting material for aid to libraries in war areas, and has already contributed 20,806 parts of periodicals from its stock of duplicates. The ultimate destination of some of the longer runs of journals is known.

The library has continued to be the collection center for books for service men and women, and by the kindness of members and friends of the Institution, has been able to send about 300 well-selected contemporary books, mostly novels, to the United Nations Service Center, and to the Public Library for distribution.

Whether in war or peace, the continuing purpose of the Smithsonian library with its branches is primarily to serve as a tool in the scientific work of the Institution. The guiding principle of its growth is not to make it a museum of fine books, but an active working reference collection. Its main function is to put into the hands of the scientific investigator the publication containing the information he needs, as nearly as possible at the moment he needs it. All the detailed and sometimes complicated processes of book selection, acquisition by purchase and exchange, classification, cataloging and arrangement, as well as the functioning of its reference and loan services are planned and carried on with this ultimate objective in mind.

Many of these processes are measurable statistically, and the number of books purchased, received by exchange and gift, cataloged, circulated, and so on, can be given, like the production figures of automobile parts. Such figures are useful indicators of material added and work done, but beyond this, the comparison with industrial output breaks down, for these library production figures cannot be finally reduced to a countable entity like a finished automobile. On the contrary, the most important end-products of the library's functioning are diffused and intangible. They become an integral part of the scientific accomplishment of the Institution itself, for they go into all its investigations in the laboratory and the field, into the identification, description, and exhibition of artifacts and specimens, into the books and papers published to advance the boundaries of scientific knowledge. The final test of successful library accomplishment is use. The mere numbers of books acquired and cataloged mean little unless the books have been discriminatingly selected for the purposes they must serve, and well and fully cataloged so that the information they contain can be easily found.

ACCESSIONS

Since the first abrupt drop in the receipt of publications from abroad after war was declared, there has been a continuous small gradual

decline in the numbers received. In 1942 there were 425 packages delivered through the International Exchange Service, in 1943 there were 355, and during the year just past, 340. From England, the South American countries, New Zealand, Australia, and South Africa the receipt of publications by mail, while somewhat fewer than before, was steady and continuous. From other allied and neutral countries mail arrived less regularly. It was especially gratifying to receive several exchange sendings of considerable numbers of current publications from the *Akademiâ Nauk* of the U. S. S. R. and its branches. Losses of material actually shipped were extremely few.

The publication of domestic scientific serials declined very little.

The reorganized accessions division functioned smoothly in handling both exchanges and purchases. The total number of volumes purchased was 1,443, and subscriptions for 240 different periodicals were entered.

A few of the most important purchases were:

For the Bureau of American Ethnology, William Coxe's "Account of the Russian Discoveries between Asia and America," 1780; "La Pérouse's Voyage round the World Performed in the Years 1785, 1786, 1787, and 1788 by the *Boussole* and *Astrolabe*," 2 volumes and atlas, 1798; and the accompanying "Voyage in Search of La Pérouse . . . during the Years 1791, 1792, 1793," by J. J. Labillardière, 1800.

For the National Collection of Fine Arts, J. J. Foster's "Miniature Painters, British and Foreign, with Some Account of Those Who Practiced in America in the Eighteenth Century," 2 volumes, 1903; F. Norfleet's "Saint-Mémin in Virginia, Portraits and Biographies," illustrated with 56 crayon portraits and 142 engravings by Saint Mémin, 1942; T. H. Ward's "Romney, a Biographical and Critical Essay, with a Catalogue Raisonné of His Works," 2 volumes, 1904.

For the National Museum, J. B. Jackson's "An Essay on the Invention of Engraving and Printing in Chiaroscuro as Practiced by Albert Dürer, Hugo di Carpi, &c . . ." 1754; "Bibliografiâ Russkii Periodicheskoi Pechati," 1703-1900, by N. M. Lisovskii, 1915; the third edition of Marc Rosenberg's "Der Goldschmiede Merkzeichen," 4 volumes, 1922-1928; Prince Nobusuke Takatsukasa's "The Birds of Nippon," parts 1-7, 1932-1939; "The Aztec and Maya Papermakers," by V. W. Von Hagen, 1943.

GIFTS

No large gifts of special collections were received, but members and friends of the Institution, as always, were generous in making contributions of important books and papers. Donors were: Dr. C. G. Abbot, R. S. Adamson, the American Association for the Advancement of Science, the American Association of Museums, the American

Council of Learned Societies, Glenn D. Angle, Miss A. Margareta Archambault, Miss Mary Dorsey Ashton, the August E. Miller Laboratories, Silvan F. Baldin, the Balfour Library, Dr. R. S. Bassler, Alexander Bierig, Miss Edna Billings, Mrs. Carl W. Bishop, Bituminous Coal Research, Inc., Col. Lawrence B. Bixby, H. H. Bloomer, Dr. Gregoria Bondar, the Book Farm, Hattiesburg, Miss., Fernando Bourquin, Dr. Adam Bøving, Dr. E. Lucy Braun, Manuel Quirós Calvo, the Canadian National Railway System, Senator José Manuel Casanova, Dr. Edward A. Chapin, Austin H. Clark, J. M. Coteló Nieva, Mariano Cuevas, William F. Davidson, H. G. Deignan, The Honorable Frederic A. Delano, Dr. Cecil H. Desch, Dr. Horace R. Descole, The Detroit News, Dr. Harold Edward Dickson, H. N. Dixon, Lauren R. Donaldson, Dr. C. J. Drake, the Engine Service and Mfg. Co., William Bacon Evans, Dr. William N. Fenton, Dr. Clarence E. Ferree, George E. Folk, Dr. Herbert Friedmann, Per K. Frolich, Dr. Samuel Wood Geiser, Haydn Thomas Giles, Ivon M. Glenne, William B. Goodwin, Jayme Fernandes Guedes, Dr. David R. Iriarte, Auguste and Edesio Irmão, Bernard Jaffe, Jewish War Veterans of the U. S., O. A. Jones, N. G. Kaye, Leon Kelso, Edwin Kirk, Laurence M. Klauber, Capt. A. M. Klum, A. J. Kupzow, Laukenau Hospital Research Institute, Gabriel Lasker, Mrs. M. P. LeRoy, H. L. Ludowyk, Miss Margaret C. McCulloch, the Manchester University Press, Ernesto Marcus, Eveline duBois-Reymond Marcus, Dr. Carlos A. Marelli, C. E. Marshall, Dr. William R. Maxon, Dr. Riley D. Moore, Père Léo-G. Morin, W. C. Muenscher, Miss Helen Munroe, Joaquim Nabuco, the National Research Council, the New York Trust Co., F. J. North, Dr. T. L. Northup, Thornton Oakley, Paul H. Oehser, Dr. A. J. Olmsted, Dr. Victor Oppenheim, Dr. Charles Owens, Parke, Davis & Company, The Pennsylvania Railroad, the Pepperell Manufacturing Co., José Perez de Barradas, William H. Phelps, the Philadelphia Child Health Society, Dr. H. Pittier, Adrien Questel, Charles D. Radford, Dr. Frank Raw, Milton Ray, Sr. Dr. Don Adrian Recinos, C. F. Richter, R. Ringuelet, Alpheus J. Roberts, B. Sahni, F. Schmid, Dr. Waldo Schmitt, J. F. Schofield, T. J. J. See, Thorvald Solberg, J. M. Stanley, H. Stehlé, Carlos Stellfeld, John R. Theaman, Dr. J. F. Torrealba, Dr. C. H. T. Townsend, the Union Diesel Engine Co., the U. S. Rocket Society, Inc., Maunsell Van Rensselaer, Dr. Egbert H. Walker, Mrs. Fiske Warren, Dr. Alexander Wetmore, Mrs. Eleanor White, W. Whittard, the Willard R. Jillson Library, the William Mitchell Printing Co., Sgt. Henry J. Young.

CATALOGING

The cataloging of current material was well kept up. Some changes in procedure and in work distribution were effective in shortening the

interval between the receipt of new publications and the completion of their preparation for use in the various libraries.

By way of a beginning in taking accurate stock of the large amount of uncataloged material in the library, three small collections of books on miscellaneous subjects, received some years ago as gifts, and numbering 2,906 volumes in all, were roughly classified and listed on cards.

PERSONNEL

There were a number of changes on the staff. Miss Josephine A. McDevitt retired on November 30, 1943, after many years spent in the service of the Institution, chiefly in the office of the International Catalogue of Scientific Literature, but after its discontinuance, in the library. Miss Elizabeth Harriet Link, the librarian's secretary, was transferred to the Freer Gallery of Art on October 9, 1943, and Mrs. Margaret K. Young was appointed to succeed her on November 16. On September 1, 1943, Mrs. Margaret L. O'Keef was appointed library assistant in the cataloging division. Mrs. Daisy F. Bishop resigned her position as library assistant on January 25, 1944, and Mrs. Marie H. Boborykine succeeded to her duties at the periodical entry desk on March 14.

Temporary appointees were Miss Ruth Newcomb, who served as library assistant in the Museum from August 24 to September 6, 1943, and Mrs. Carmen G. Randall who succeeded her on September 30.

There were upward reclassifications of the positions of Miss Miriam B. Ketchum, librarian in charge of the Bureau of American Ethnology library, of Mrs. Mary A. Baer, librarian in charge of the Arts and Industries branch of the Museum library, of Miss Marie Ruth Wenger, in charge of cataloging in the Museum, and of Samuel Jones, messenger.

STATISTICS

Accessions

	Volumes	Total holdings June 30, 1944
Astrophysical Observatory (including Radiation and Organisms).....	214	11,508
Bureau of American Ethnology.....	120	34,001
Freer Gallery of Art.....	105	16,636
Langley Aeronautical Library.....	18	3,610
National Collection of Fine Arts.....	651	9,745
National Museum.....	3,726	230,693
National Zoological Park.....	44	4,087
Smithsonian Deposit.....	812	571,840
Smithsonian Office.....	211	31,493
Total.....	5,971	1,913,616

¹ Neither incomplete volumes of periodicals nor separates and reprints from periodicals are included in these figures.

Exchanges

New exchanges arranged.....	104
44 of these were assigned to the Smithsonian Deposit.	
"Wants" received.....	4,422
656 of these were obtained to fill gaps in the Smithsonian Deposit sets.	

Cataloging

Volumes and pamphlets cataloged.....	6,673
Cards filed in catalogs and shelflists.....	41,929

Periodicals

Periodical parts entered.....	11,480
3,181 of these were sent to the Smithsonian Deposit.	

Circulation

Loans of books and periodicals.....	11,300
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This figure does not include the very considerable intramural circulation of books and periodicals assigned to sectional libraries for filing, of which no count is kept.

Binding

Volumes sent to the bindery.....	1,683
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Respectfully submitted.

LEILA F. CLARK, *Librarian.*

THE SECRETARY,
Smithsonian Institution.

APPENDIX 10

REPORT ON PUBLICATIONS

SIR: I have the honor to submit the following report on the publications of the Smithsonian Institution and the Government branches under its administrative charge during the year ended June 30, 1944.

The Institution published during the year 4 papers in the Smithsonian Miscellaneous Collections; 7 papers in the War Background Studies series; 1 Annual Report of the Board of Regents and pamphlet copies of 20 articles in the Report appendix; 1 Annual Report of the Secretary; 2 special publications; reprints of 2 papers in the Miscellaneous Collections and 1 special publication, and additional copies of 1 volume of tables.

The United States National Museum issued 1 Annual Report; 14 Proceedings papers; 4 Bulletins; 1 separate paper in the Bulletin series of Contributions from the United States National Herbarium.

The Bureau of American Ethnology issued 1 Annual Report and 6 Bulletins.

The Freer Gallery of Art issued 1 pamphlet.

Of the publications there were distributed 172,027 copies, which included 54 volumes and separates of Smithsonian Contributions to Knowledge, 12,966 volumes and separates of Smithsonian Miscellaneous Collections, 21,416 volumes and separates of Smithsonian Annual Reports, 75,749 War Background Studies papers, 4,911 Smithsonian special publications, 23 reports on the Harriman Alaska Expedition, 40,817 volumes and separates of National Museum publications, 14,903 publications of the Bureau of American Ethnology, 9 catalogs of the National Collection of Fine Arts, 2 pamphlets of the Freer Gallery of Art, 23 Annals of the Astrophysical Observatory, and 1,124 reports of the American Historical Association.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

Four papers in this series were issued, as follows:

VOLUME 104

No. 1. The feeding apparatus of biting and disease-carrying flies: A wartime contribution to medical entomology, by R. E. Snodgrass. 51 pp., 18 figs. (Publ. 3732.) July 19, 1943.

No. 2. Cross sections of New World prehistory: A brief report on the work of the Institute of Andean Research, 1941-1942, by William Duncan Strong. 46 pp., 33 pls., 1 fig. (Publ. 3739.) December 21, 1943.

No. 3. A 27-day period in Washington precipitation, by C. G. Abbot. 4 pp., 1 fig. (Publ. 3765.) February 3, 1944.

No. 4. The influence of light and of carbon dioxide on the respiration of etiolated barley seedlings, by Robert L. Weintraub and Earl S. Johnston. 16 pp., 2 pls., 8 figs. (Publ. 3769.) June 28, 1944.

The following Miscellaneous Collections papers were reprinted:

VOLUME 86

Smithsonian Meteorological Tables. Fifth Revised Edition. First Reprint (additional copies printed without change). lxxxvi+282 pp. (Publ. 3116.)

VOLUME 95

No. 5. Molluscan intermediate hosts of the Asiatic blood fluke, *Schistosoma japonicum*, and species confused with them, by Paul Bartsch. 60 pp., 8 pls. (With description of 2 new species, 5 pp., 2 figs.) (Publ. 3384.)

VOLUME 104

No. 1. The feeding apparatus of biting and disease-carrying flies: A wartime contribution to medical entomology, by R. E. Snodgrass. 51 pp., 18 figs. (Publ. 3732.)

WAR BACKGROUND STUDIES

In this new series of Smithsonian publications, there were issued during the year the following 7 papers:

No. 13. Alaska: America's continental frontier outpost, by Ernest P. Walker. 21 pp., 21 pls., 2 figs. (Publ. 3733.) July 8, 1943.

No. 14. Islands and peoples of the Indies, by Raymond Kennedy. 66 pp., 21 pls., 7 figs. (Publ. 3734.) August 5, 1943.

No. 15. Iceland and Greenland, by Austin H. Clark. 103 pp., 21 pls., 2 figs. (Publ. 3735.) August 19, 1943.

No. 16. Island peoples of the western Pacific: Micronesia and Melanesia, by Herbert W. Krieger. 104 pp., 21 pls., 2 figs. (Publ. 3737.) September 15, 1943.

No. 17. Burma—Gateway to China, by H. G. Deignan. 21 pp., 16 pls., 1 fig. (Publ. 3738.) October 29, 1943.

No. 18. Peoples of India, by William H. Gilbert. 86 pp., 21 pls., 3 figs. (Publ. 3767.) April 29, 1944.

No. 19. The peoples of French Indochina, by Olov R. T. Janse. 28 pp., 25 pls., 1 fig. (Publ. 3768.) June 12, 1944.

War Background Studies No. 20, "China," by Archibald C. Wenley and John A. Pope, was in press at the close of the fiscal year.

SMITHSONIAN ANNUAL REPORTS

Report for 1942.—The complete volume of the Annual Report of the Board of Regents for 1942 was received from the Public Printer on September 24, 1943.

Annual Report of the Board of Regents of the Smithsonian Institution showing the operations, expenditures, and condition of the Institution for the year ended June 30, 1942. xiii+421 pp., 83 pls., 44 figs. (Publ. 3705.) 1943.

The general appendix contained the following papers (Publs. 3706-3725):

- The 1914 tests of the Langley "aerodrome," by C. G. Abbot.
- The problem of the expanding universe, by Edwin Hubble.
- Galaxies, by Harlow Shapley.
- Is there life on the other worlds? by Sir James Jeans.
- Solar radiation and the state of the atmosphere, by Harlan True Stetson.
- The sun and the earth's magnetic field, by J. A. Fleming.
- Ultraviolet light as a sanitary aid, by Louis Gershenfeld.
- Trends in petroleum geology, by A. I. Levorsen.
- Meteorites and their metallic constituents, by E. P. Henderson and Stuart H. Perry.
- Philippine tektites and the tektite problem in general, by H. Otley Beyer.
- Chemical properties of viruses, by W. M. Stanley.
- Industrial development of synthetic vitamins, by Randolph T. Major.
- The nutritional requirements of man, by C. A. Elvehjem.
- Past and present status of the marine mammals of South America and the West Indies, by Remington Kellogg.
- The return of the musk ox, by Stanley P. Young.
- Insect enemies of our cereal crops, by C. M. Packard.
- The geographical aspects of malaria, by Sir Malcolm Watson.
- The bromeliads of Brazil, by Milford B. Foster.
- Canada's Indian problems, by Diamond Jenness.
- Dakar and the other Cape Verde settlements, by Derwent Whittlesey.

Report for 1943.—The Report of the Secretary, which included the financial report of the executive committee of the Board of Regents, and which will form part of the Annual Report of the Board of Regents to Congress, was issued December 21, 1943.

Report of the Secretary of the Smithsonian Institution and financial report of the executive committee of the Board of Regents for the year ended June 30, 1943. ix+95 pp., 2 pls. (Publ. 3740.) 1943.

The Report volume, containing the general appendix, was in press at the close of the year.

SPECIAL PUBLICATIONS

Classified list of Smithsonian publications available for distribution October 1, 1943, by Helen Munroe. 47 pp. (Publ. 3736.) October 1, 1943.

A field collector's manual in natural history, by members of the staff of the Smithsonian Institution. 118 pp., 66 figs. (Publ. 3766.) April 26, 1944.

The following special publication was reprinted:

Handbook of the National Aircraft Collection, by Paul E. Garber. Fifth Edition. 43 pp., 26 pls., 1 fig. (Publ. 3635.)

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM

The editorial work of the National Museum has continued during the year under the immediate direction of the editor, Paul H. Oehser. There were issued 1 Annual Report, 14 Proceedings papers, 4 Bulletins, and 1 separate paper in the Bulletin series of Contributions from the United States National Herbarium, as follows:

MUSEUM REPORT

Report on the progress and condition of the United States National Museum for the fiscal year ended June 30, 1943. iii+108 pp. January 1944.

PROCEEDINGS: VOLUME 91

Title page, table of contents, and index. Pp. i-viii, 521-529. October 26, 1943.

VOLUME 92

Title page, table of contents, and index. Pp. i-viii, 621-668. November 29, 1943.

VOLUME 93

No. 3167. New species of buprestid beetles of the genus *Agilus* from Trinidad, by W. S. Fisher. Pp. 375-380. July 26, 1943.

No. 3168. Some fungus beetles of the family Endomychidae in the United States National Museum, mostly from Latin America and the Philippine Islands, by H. F. Strohecker. Pp. 381-392, fig. 12. August 5, 1943.

No. 3169. Summary of the collections of snakes and crocodilians made in Mexico under the Walter Rathbone Bacon travelling scholarship, by Hobart M. Smith. Pp. 393-504, figs. 13-15, pl. 32. October 29, 1943.

No. 3170. The North American parasitic wasps of the genus *Tetrastichus*—A contribution to biological control of insect pests, by B. D. Burks. Pp. 505-608, figs. 16-21. October 26, 1943.

Title page, table of contents, and index. Pp. i-viii, 609-647. April 13, 1944.

VOLUME 94

No. 3171. Catalog of human crania in the United States National Museum collections: Non-Eskimo people of the Northwest coast, Alaska, and Siberia, by Aleš Hrdlička. Pp. 1-172. April 6, 1944.

No. 3172. The catfishes of Venezuela, with descriptions of thirty-eight new forms, by Leonard P. Schultz. Pp. 173-338, figs. 1-5, pls. 1-14. February 11, 1944.

No. 3173. Revisions of two genera of chalcid-flies belonging to the family Eupelmidae from North and South America, by A. B. Gahan. Pp. 339-369. November 26, 1943.

No. 3174. New species of American scolytoid beetles, mostly Neotropical, by M. W. Blackman. Pp. 371-399, pls. 15-17. November 22, 1943.

No. 3175. A revision of the Embloptera, or web-spinners, of the New World, by Edward S. Ross. Pp. 401-504, figs. 6-156, pls. 18-19. January 19, 1944.

No. 3176. Twelve new species of Chinese leaf-katydids of the genus *Xiphidiopsis*, by Ernest R. Tinkham. Pp. 505-527, fig. 157. April 29, 1944.

VOLUME 95

No. 3178. New American cynipids from galls, by Lewis H. Weld. Pp. 1-24. pls. 1-2. April 15, 1944.

BULLETINS

No. 183. Archeological investigations in Platte and Clay Counties, Missouri, by Waldo R. Wedel. With appendix, Skeletal remains from Platte and Clay Counties, Missouri, by T. Dale Stewart. viii+284 pp., 22 figs., 50 pls. October 1, 1943.

No. 184. The metallography of meteoric iron, by Stuart H. Perry. viii+206 pp., 9 figs., 78 pls. February 15, 1944.

No. 185, part 1. Checklist of the coleopterous insects of Mexico, Central America, the West Indies, and South America, compiled by Richard E. Blackwelder. xii+188 pp. March 7, 1944.

No. 185, part 2. Checklist of the coleopterous insects of Mexico, Central America, the West Indies, and South America, compiled by Richard E. Blackwelder. Pp. 189-341. June 30, 1944.

CONTRIBUTIONS FROM THE UNITED STATES NATIONAL HERBARIUM
VOLUME 29

Part 1. Taxonomic studies of tropical American plants, by C. V. Morton. Pp. 1-xi, 1-86. March 23, 1944.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY

The editorial work of the Bureau has continued under the immediate direction of the editor, M. Helen Palmer. During the year there were issued 1 Annual Report and 6 Bulletins, as follows:

REPORT

Sixtieth Annual Report of the Bureau of American Ethnology, 1942-1943. 9 pp. January 1944.

BULLETINS

133. Anthropological papers, numbers 19-26. ix+615 pp., 34 pls., 62 figs. 1943.

No. 19. A search for songs among the Chitimacha Indians in Louisiana, by Frances Densmore.

No. 20. Archeological survey on the northern Northwest coast, by Phillip Drucker; with appendix, Early vertebrate fauna of the British Columbia coast, by Edna M. Fisher.

No. 21. Some notes on a few sites in Beaufort County, South Carolina, by Regina Flannery.

No. 22. An analysis and interpretation of the ceramic remains from two sites near Beaufort, South Carolina, by James R. Griffin.

No. 23. The eastern Cherokees, by William Harlan Gilbert, Jr.

No. 24. Aconite poison whaling in Asia and America: An Aleutian transfer to the New World, by Robert F. Helzer.

No. 25. The Carrier Indians of the Bulkley River: Their social and religious life, by Diamond Jenness.

No. 26. The qulpu and Peruvian civilization, by John R. Swanton.

136. Anthropological papers, numbers 27-32. viii+375 pp., 32 pls., 5 figs. 1943.

No. 27. Music of the Indians of British Columbia, by Frances Densmore.

No. 28. Choctaw music, by Frances Densmore.

No. 29. Some ethnological data concerning one hundred Yucatan plants, by Morris Steggerda.

No. 30. A description of thirty towns in Yucatan, Mexico, by Morris Steggerda.

No. 31. Some western Shoshoni myths, by Julian H. Steward.

No. 32. New material from Acoma, by Leslie A. White.

138. Stone monuments of southern Mexico, by Matthew W. Stirling. vii+84 pp., 62 pls., 14 figs. 1943.

139. An introduction to the ceramics of Tres Zapotes, Veracruz, Mexico, by C. W. Weiant. xiv+144 pp., 78 pls., 54 figs., 10 maps. 1943.

140. Ceramic sequences at Tres Zapotes, Veracruz, Mexico, by Phillip Drucker. ix+155 pp., 65 pls., 46 figs. 1943.

141. Ceramic stratigraphy at Cerro de las Mesas, Veracruz, Mexico, by Phillip Drucker. viii+95 pp., 58 pls., 210 figs. 1943.

PUBLICATIONS OF THE FREER GALLERY OF ART

The Freer Gallery of Art issued 1 pamphlet, as follows:

The Freer Gallery of Art of the Smithsonian Institution. 12 pp., 5 pls., 2 figs. January 1944.

REPORT OF THE AMERICAN HISTORICAL ASSOCIATION

The annual reports of the American Historical Association are transmitted by the Association to the Secretary of the Smithsonian Institution and are communicated by him to Congress, as provided by the act of incorporation of the Association. The following report volumes were issued this year:

Annual Report of the American Historical Association for the year 1942. Volume 1. Proceedings and list of members; Volume 2. Letters from the Berlin Embassy.

The following were in press at the close of the fiscal year: Annual Report for 1942, Volume 3 (The quest for political unity in world history); Annual Report for 1943, Volume 1 (Proceedings) and Volume 2 (Writings on American History).

REPORT OF THE NATIONAL SOCIETY, DAUGHTERS OF THE AMERICAN REVOLUTION

The manuscript of the Forty-sixth Annual Report of the National Society, Daughters of the American Revolution, was transmitted to Congress, in accordance with law, November 15, 1943.

ALLOTMENTS FOR PRINTING

The congressional allotments for the printing of the Smithsonian Annual Reports to Congress and the various publications of the Government bureaus under the administration of the Institution were virtually used up at the close of the year. The appropriation for the coming year ending June 30, 1945, totals \$88,500, allotted as follows:

Smithsonian Institution.....	\$16,000
National Museum.....	43,000
Bureau of American Ethnology.....	17,480
National Collection of Fine Arts.....	500
International Exchanges.....	200
National Zoological Park.....	200
Astrophysical Observatory.....	500
American Historical Association.....	10,620
Total.....	88,500

Respectfully submitted.

W. P. TRUE, *Chief, Editorial Division.*

THE SECRETARY,
Smithsonian Institution.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITH- SONIAN INSTITUTION

FOR THE YEAR ENDED JUNE 30, 1944

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds of the Smithsonian Institution, together with a statement of the appropriations by Congress for the Government bureaus in the administrative charge of the Institution.

SMITHSONIAN ENDOWMENT FUND

The original bequest of James Smithson was £104,960 8s. 6d.—\$508,318.46. Refunds of money expended in prosecution of the claim, freights, insurance, etc., together with payment into the fund of the sum of £5,015, which had been withheld during the lifetime of Madame de la Batut, brought the fund to the amount of \$550,000.

Since the original bequest the Institution has received gifts from various sources chiefly in the years prior to 1893, the income from which may be used for the general work of the Institution. These, including the original bequest, plus savings, are listed below, together with the income for the present year.

ENDOWMENT FUNDS

(Income for unrestricted use of the Institution)

Partly deposited in U. S. Treasury at 6 percent and partly invested in stocks, bonds, etc.

	Investment	Income present year
Parent fund (original Smithson bequest, plus accumulated savings).....	\$728,843.38	\$43,700.77
Subsequent bequests, gifts, etc., partly deposited in the U. S. Treasury and partly invested in the Consolidated Fund:		
Avery, Robert S. and Lydia, bequest fund.....	50,766.70	2,133.13
Endowment, from gifts, income, etc.....	283,751.87	9,988.86
Habel, Dr. S., bequest fund.....	600.00	30.00
Hachenberg, George P. and Caroline, bequest fund.....	3,971.01	139.66
Hamilton, James, bequest fund.....	2,898.60	164.00
Henry, Caroline, bequest fund.....	1,194.17	41.98
Hodgkins, Thomas G., fund (general).....	143,841.56	8,069.54
Rhees, William Jones, bequest fund.....	1,057.12	51.80
Sanford, George H., memorial fund.....	1,978.97	96.89
Witherspoon, Thomas A., memorial fund.....	137,421.29	4,481.58
Special fund, stock in reorganized closed banks.....	1,400.00	70.00
	630,781.29	25,207.44
Total.....	1,349,626.67	68,908.51

The Institution holds also a number of endowment gifts, the income of each being restricted to specific use. These, plus accretions to date, are listed below, together with income for the present year.

	Investment	Income present year
Abbott, William L., fund, for investigations in biology.....	\$104,598.38	\$3,348.29
Arthur, James, fund, for investigations and study of the sun and lecture on same.....	39,498.66	1,388.87
Bacon, Virginia Purdy, fund, for traveling scholarship to investigate fauna of countries other than the United States.....	40,468.47	1,739.86
Baird, Lucy H., fund, for creating a memorial to Secretary Baird.....	23,772.94	841.19
Barnstow, Frederick D., fund, for purchase of animals for the Zoological Park.....	751.09	26.40
Canfield Collection fund, for increase and care of the Canfield collection of minerals.....	37,764.34	1,328.20
Casey, Thomas L., fund, for maintenance of the Casey collection and promotion of researches relating to Coleoptera.....	9,036.58	318.52
Chamberlain, Francis Lea, fund, for increase and promotion of Isaac Lea collection of gems and mollusks.....	27,805.06	977.94
Eickemeyer, Florence Brevoort, fund, for preservation and exhibition of photographic collection of Rudolph Eickemeyer, Jr.....	500.92	4.43
Hillyer, Virgil, fund, for increase and care of Virgil Hillyer collection of lighting objects.....	6,480.28	228.20
Hillebreck, Dr. Albert S., Library fund, for care of Hillebreck Agrostological Library.....	1,459.30	51.30
Hodgkins fund, specific, for increase and diffusion of more exact knowledge in regard to nature and properties of atmospheric air.....	100,000.00	6,000.00
Hughes, Bruce, fund, to found Hughes alcove.....	18,869.72	664.70
Myer, Catherine Walden, fund, for purchase of first-class works of art for the use and benefit of the National Collection of Fine Arts.....	18,714.49	658.29
National Collection of Fine Arts, Julia D. Strong bequest, for the benefit of National Collection of Fine Arts.....	9,871.78	347.18
Pell, Cornelia Livingston, fund, for maintenance of Alfred Drane Pell collection.....	7,318.99	267.40
Poore, Lucy T. and George W., fund, for general use of the Institution when principal amounts to the sum of \$250,000.00.....	92,290.68	3,907.33
Reid, Addison T., fund, for founding chair in biology in memory of Asber Tunis.....	29,808.86	1,390.37
Roebling fund, for care, improvement, and increase of Roebling collection of minerals.....	119,165.01	4,191.20
Rollins, Miriam and William, fund, for investigations in physics and chemistry.....	92,724.31	3,249.78
Smithsonian employees retirement fund.....	45,193.31	1,389.07
Springer, Frank, fund, for care, etc., of Springer collection and library.....	17,709.50	622.75
Walcott, Charles D. and Mary Vaux, research fund, for development of geological and paleontological studies and publishing results thereof.....	427,479.27	13,034.00
Younger, Helen Walcott, fund, held in trust.....	49,628.70	2,398.93
Zerbe, Frances Brackley, fund, for endowment for aquaria.....	751.47	26.40
Special research fund, gift, in the form of real estate (no income).....	20,946.00	
Total.....	1,351,693.81	48,578.50

The above funds amount to a total of \$2,701,320.48, and are carried in the following investment accounts of the Institution:

U. S. Treasury deposit account, drawing 6 percent interest.....	\$1,000,000.00
Consolidated investment fund (income in table below).....	1,372,516.41
Real estate, mortgages, etc.....	277,775.37
Special funds, miscellaneous investments.....	51,028.70
	2,701,320.48

CONSOLIDATED FUND

This fund contains substantially all of the investments of the Institution, with the exception of those of the Freer Gallery of Art; the deposit of \$1,000,000.00 in the U. S. Treasury, with guaranteed income of 6 percent; and investments in real estate and real estate mortgages.

This fund contains endowments for both unrestricted and specific use. A statement of principal and income of this fund for the last 10 years follows:

Fiscal year	Principal	Income	Per- cent- age	Fiscal year	Principal	Income	Per- cent- age
1935.....	\$706,765.68	\$26,808.86	3.79	1940.....	\$1,081,249.25	\$38,673.29	3.47
1936.....	723,704.46	26,836.61	3.71	1941.....	1,093,301.51	41,167.38	3.76
1937.....	738,858.54	33,519.43	4.57	1942.....	1,270,968.45	46,701.98	3.67
1938.....	867,528.50	34,679.64	4.00	1943.....	1,316,533.49	50,524.22	3.83
1939.....	902,801.27	30,710.53	3.40	1944.....	1,372,516.41	50,783.79	3.69

CONSOLIDATED FUND

Gain in Investments over year 1943

Investments made from gifts and savings on income.....	\$46,061.80
Investments of gain from sales., etc., of securities.....	9,921.12

55,982.92

FREER GALLERY OF ART FUND

Early in 1906, by deed of gift, Charles L. Freer, of Detroit, gave to the Institution his collection of Chinese and other Oriental objects of art, as well as paintings, etchings, and other works of art by Whistler, Thayer, Dewing, and other artists. Later he also gave funds for the construction of a building to house the collection, and finally in his will probated November 6, 1919, he provided stock and securities to the estimated value of \$1,958,591.42, as an endowment fund for the operation of the Gallery.

The above fund of Mr. Freer was almost entirely represented by 20,465 shares of stock in Parke, Davis & Co. As this stock advanced in value, much of it was sold and the proceeds reinvested so that the fund now amounts to approximately three times the original value, or \$5,881,402.17, in a selected list of securities classified later.

The invested funds of the Freer bequest are under the following headings:

Court and grounds fund.....	\$658,864.68
Court and grounds maintenance fund.....	165,479.65
Curator fund.....	670,500.62
Residuary legacy.....	4,386,557.22
Total.....	5,881,402.17

Statement of principal and income for the last 10 years

Fiscal year	Principal	Income	Per- cent- age	Fiscal year	Principal	Income	Per- cent- age
1935.....	\$4,780,362.53	\$257,510.33	5.39	1940.....	\$6,112,063.46	\$242,673.92	3.96
1936.....	4,651,867.07	259,429.73	5.57	1941.....	6,080,566.91	233,079.22	3.86
1937.....	4,881,986.96	280,040.53	5.75	1942.....	5,912,878.64	241,037.77	4.08
1938.....	4,820,777.31	255,651.61	5.30	1943.....	5,836,772.01	216,128.07	3.70
1939.....	5,073,976.76	212,751.78	4.19	1944.....	5,881,402.17	212,393.27	3.61

FREER FUND

Gain in investments over year 1943

Investment of gain from sale, call of securities, etc.....	\$44,630.16
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SUMMARY

Invested endowment for general purposes.....	\$1,349,026.67
Invested endowment for specific purposes other than Freer endowment.....	1,351,003.81
Total invested endowment other than Freer endowment.....	2,701,320.48
Freer invested endowment for specific purposes.....	5,881,402.17
Total invested endowment for all purposes.....	8,582,722.65

CLASSIFICATION OF INVESTMENTS

Deposited in the U. S. Treasury at 6 percent per annum, as authorized in the United States Revised Statutes, sec. 5591.....	\$1,000,000.00
Investments other than Freer endowment (cost or market value at date acquired) :	
Bonds (15 different groups).....	\$592,791.43
Stocks (43 different groups).....	901,420.91
Real estate and first-mortgage notes.....	200,604.24
Uninvested capital.....	509.90
	1,701,320.48
Total investments other than Freer endowment.....	2,701,320.48
Investments of Freer endowment (cost or market value at date acquired) :	
Bonds (25 different groups).....	\$2,617,447.75
Stocks (52 different groups).....	3,250,673.19
Real estate first-mortgage notes.....	7,000.00
Uninvested capital.....	6,281.23
	\$5,881,402.17
Total investments.....	8,582,722.65

CASH BALANCES, RECEIPTS, AND DISBURSEMENTS DURING THE FISCAL YEAR¹

Cash balance on hand June 30, 1943.....	\$671,698.43
Receipts :	
Cash income from various sources for general work of the Institution.....	\$85,530.75
Cash gifts and contributions expendable for special scientific objects (not for investment).....	75,419.86
Cash income from endowments for specific use other than Freer endowment and from miscellaneous sources (including refund of temporary advances).....	127,400.84
Cash capital from sale, call of securities, etc. (for investment).....	220,962.85
Total receipts other than Freer endowment.....	509,374.30

¹ This statement does not include Government appropriations under the administrative charge of the Institution.

CASH BALANCES, RECEIPTS, AND DISBURSEMENTS DURING THE
FISCAL YEAR—Continued

Receipts—Continued.

Cash income from Freer endowment.....	\$210, 663. 89	
Cash capital from sale, call of securities, etc. (for investment)	710, 039. 26	
Total receipts from Freer endowment.....		\$920, 703. 15
Total.....		2, 101, 775. 88

Disbursements:

From funds for general work of the Institution:

Buildings—care, repairs, and alterations....	\$3, 246. 87	
Furniture and fixtures.....	33. 90	
General administration ²	34, 955. 20	
Library.....	3, 025. 26	
Publications (comprising preparation, printing, and distribution).....	31, 943. 79	
Researches and explorations.....	11, 703. 21	
		\$84, 908. 23

From funds for specific use, other than Freer endowment:

Investments made from gifts and from savings on income.....	46, 061. 80	
Other expenditures, consisting largely of research work, travel, increase and care of special collections, etc., from income of endowment funds, and from cash gifts for specific use (including temporary advances).....	118, 461. 61	
Reinvestment of cash capital from sale, call of securities, etc.....	226, 609. 13	
Cost of handling securities, fee of investment counsel, and accrued interest on bonds purchased.....	2, 971. 51	
		304, 104. 05

From Freer endowment:

Operating expenses of the gallery, salaries, field expenses, etc.....	45, 764. 82	
Purchase of art objects.....	126, 774. 81	
Reinvestment of cash capital from sale, call of securities, etc.....	709, 947. 31	
Cost of handling securities, fee of investment counsel, and accrued interest on bonds purchased.....	20, 962. 18	
		903, 449. 12
Cash balance June 30, 1944.....		719, 314. 48

Total..... 2, 101, 775. 88

Included in the above receipts was cash received as royalties from sales of Smithsonian Scientific Series to the amount of \$21,150.31.

² This includes salary of the Secretary and certain others.

This was distributed as follows:

Endowment fund.....	\$9,127.36
Smithsonian Institution emergency fund.....	2,281.84
Smithsonian Institution unrestricted fund, general.....	6,845.51
Salaries.....	2,895.60
	<hr/>
	21,150.31

Included in the foregoing are expenditures for researches in pure science, publications, explorations, care, increase, and study of collections, etc., as follows:

Expenditures from general funds of the Institution:

Publications.....	\$31,943.79
Researches and explorations.....	11,703.21
	<hr/>
	\$43,647.00

Expenditures from funds devoted to specific purposes:

Researches and explorations.....	20,355.18
Care, increase, and study of special collections.....	7,422.06
Publications.....	7,984.60
	<hr/>
	44,761.84

Total.....	<hr/>	88,408.84
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The practice of depositing on time in local trust companies and banks such revenues as may be spared temporarily has been continued during the past year, and interest on these deposits has amounted to \$657.15.

The Institution gratefully acknowledges gifts or bequests from the following:

Carnegie Institution, for the support and maintenance of diatom studies.

Thomas G. Corcoran, toward the purchase of portrait of George Washington Carver.

Edith F. B. and George B. Engelhardt, for assistance in publication of bulletin by the late George B. Engelhardt.

Friends of Dr. Albert S. Hitchcock, for the Hitchcock Agrostological Library.

John A. Roebling, further contributions for research in radiation.

All payments are made by check, signed by the Secretary of the Institution on the Treasurer of the United States, and all revenues are deposited to the credit of the same account. In many instances deposits are placed in bank for convenience of collection and later are withdrawn in round amounts and deposited in the Treasury.

The foregoing report relates only to the private funds of the Institution.

The following annual appropriations were made by Congress for the Government bureaus under the administrative charge of the Smithsonian Institution for the fiscal year 1944.

Salaries and Expenses, 1944.....	\$1,129,040.00
National Zoological Park, D. C., 1944.....	270,130.00
Cooperation with the American Republics (transfer to the Smithsonian Institution), 1944.....	77,000.00

A deficiency appropriation of \$57,000 was also made by Congress to pay Federal employees for overtime work.

The report of the audit of the Smithsonian private funds is given below:

SEPTEMBER 30, 1944.

EXECUTIVE COMMITTEE, BOARD OF REGENTS,

Smithsonian Institution, Washington, D. C.

SIRS: Pursuant to agreement we have audited the accounts of the Smithsonian Institution for the fiscal year ended June 30, 1944, and certify that the balance of cash on hand, including Petty Cash Fund, June 30, 1944, to be \$721,214.48.

We have verified the record of receipts and disbursements maintained by the Institution and the agreement of the book balances with the bank balances.

We have examined all the securities in the custody of the Institution and in the custody of the banks and found them to agree with the book records.

We have compared the stated income of such securities with the receipts of record and found them in agreement therewith.

We have examined all vouchers covering disbursements for account of the Institution during the fiscal year ended June 30, 1944, together with the authority therefor, and have compared them with the Institution's record of expenditures and found them to agree.

We have examined and verified the accounts of the Institution with each trust fund.

We found the books of account and records well and accurately kept and the securities conveniently filed and securely cared for.

All information requested by your auditors was promptly and courteously furnished.

We certify the Balance Sheet, in our opinion, correctly presents the financial condition of the Institution as at June 30, 1944.

Respectfully submitted.

WILLIAM L. YAEGER,
Certified Public Accountant.

Respectfully submitted.

FREDERIC A. DELANO,
VANNEVAR BUSH,
CLARENCE CANNON,
Executive Committee.

GENERAL APPENDIX
TO THE
SMITHSONIAN REPORT FOR 1944

ADVERTISEMENT

The object of the **GENERAL APPENDIX** to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution from a very early date to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and, during the greater part of its history, this purpose has been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880, induced in part by the discontinuance of an annual summary of progress which for 30 years previously had been issued by well-known private publishing firms, the Secretary had a series of abstracts prepared by competent collaborators, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1944.

SOLAR VARIATION AND WEATHER ¹

By CHARLES G. ABBOT
Former Secretary, Smithsonian Institution

[With 2 plates]

NATURE OF THE SUN

The sun is a gaseous body 860,000 miles in diameter of about 330,000 times the mass of the earth. Though so hot that neither solids nor liquids exist in it, the force of gravity due to its enormous mass compresses the sun's gaseous substance to an average density nearly 1.5 times that of water, or nearly 1,100 times that of air at sea level. This density prevails, notwithstanding that the great temperature not only gasifies the chemical elements, but still further subdivides them by ionizing them strongly. They are no longer composed of molecules, like gaseous substances that we find in the laboratory, or even complete atoms, for the atomic nuclei have lost some of the ions which at lower temperatures would surround them to make up complete atoms. The surface temperature of the sun is of the order 6,000° Centigrade, or 10,800° Fahrenheit, nearly twice as hot as the arc light. Within the sun the temperature rapidly rises, and at the sun's center it is supposed to be many millions of degrees. At such enormous temperatures and with its immense surface, the sun is a tremendously powerful radiator, so powerful that at the earth's mean distance, 93,000,000 miles, the sun's average radiation in free space measures 1.94 calories per cm.² per minute. This value is called the solar constant of radiation. It implies that the earth, which is about 8,000 miles in diameter, receives all the time from the sun the heat equivalent to a quarter of a quadrillion horsepower ($10^{15}/4$ hp.)

SOLAR ROTATION

The sun, like the earth, rotates on an axis. The sun's axis is not exactly parallel to the earth's, but inclines toward a point halfway between the Pole Star and Vega at 26° from the North Pole. It has

¹ The twelfth Arthur lecture given under the auspices of the Smithsonian Institution, February 29, 1944.

been observed by spectroscopic methods that the angular rotation of the sun's surface is much faster at the Equator than near the Poles. Adams found the following times of rotation as viewed from a fixed star:

Solar latitude.....	0°	30°	45°	60°	80°
Rotation period.....	24.7	26.7	28.0	31.2	35.3

The earth revolves about the sun in 365¼ days, and approximately in the same direction that the sun rotates on its axis. Consequently the solar rotation appears slower as viewed from the earth, which adds over 7 percent to the sun's apparent time of rotation. The effective mean period of solar rotation viewed from the earth may be taken as 27 days.

FACULAE AND SUNSPOTS

In a telescope, as shown in plate 1, the sun's surface is seen to be mottled, but at some places to show decidedly brighter areas called faculae which are most prevalent in the neighborhood of sunspots. Sunspots appear as darker dots on the sun's surface, but they are dark only by contrast. Langley compared the faculae to white-hot steel in a converter, which made the molten steel look like chocolate. Though sunspots appear small on the enormous disk of the sun, actually many of them are so large that the earth, 8,000 miles in diameter, would only occupy a corner of one. Sunspots are seldom within 10° of the sun's equator or more than 30° away from it. They, of course, rotate along with the surface of the sun at such latitudes, and their average time of rotation is about 27 days, as viewed from the earth.

SOLAR VARIATION AND SOLAR ROTATION

Sunspots are like machine guns shooting electric ions into space. These ions plentifully strike and are captured by the earth's atmosphere. With ions from other sources they make up that high-level electrical reflecting surface in our atmosphere which causes radio rays to bounce along the surface of the earth for thousands of miles, instead of losing themselves at once into limitless space. As the sun rotates on its axis the conical columns of flying ions sent out from sunspots sweep through space. The columns from those spots which are nearly central on the sun's apparent disk encounter the earth for the short time of 2 or 3 days. From certain observations we made in March 1920, it seems that such a column of ions, 93 million miles long between the sun and the earth, by scattering the sun's rays sometimes reduces the intensity of the sun beam at the earth by as much as 5 percent. Ordinarily such effects are much less, seldom exceeding 1 percent. But it is easy to see that the rotation of a spotted sun, by ionic scattering, may produce successions of small variations of the solar

constant of radiation. The presence of areas of faculae, hotter and more radiative than the adjoining solar surfaces, will also, as they march around with the sun's rotation, produce variations of the solar constant.

THE EARTH'S TEMPERATURE

The earth as a planet is kept in its present approximately constant state at the mean temperature of 14° Centigrade by the balance of its receipt of heat from sun rays against the outgo of heat caused by the earth's emission to space. This earth emission arises in the invisible long-wave rays which lie between the gamut of visible light and the gamut of rays of very great wave length, which are used in radio transmission. To fix ideas in terms of the centimeter, the unit of length in the metric system, visible light rays have wave lengths between 4 and 7 hundred-thousandths (0.00004 and 0.00007), earth rays between 4 and 40 ten-thousandths (0.0004 and 0.0040), and radio rays between 10 and 1 million (10 and 1,000,000) centimeters. But all of them are of the same fundamental nature of transverse vibrations.

Since the earth's mean temperature keeps within fairly definite bounds because the total receipt of heat from the sun is in approximate equilibrium with the total escape of heat from the earth, it is plain that if the sun's contribution should change permanently, the earth's mean temperature would change to a new state of equilibrium. However, the sun is so immense that no considerable general change of this kind is to be apprehended in thousands, or even millions, of years. Nevertheless, in what follows it will be shown that temporary changes of the order of 1 percent do frequently occur in the sun's output, and that these affect weather locally so much that solar changes must be rated as major meteorological factors.

SMITHSONIAN SOLAR-CONSTANT WORK

For many years the Smithsonian Institution has maintained observatories for measuring the intensity of solar rays. Our best station is Montezuma, in the Atacama Desert of northern Chile. It is located on a mountain 9,000 feet high, where years frequently go by without a drop of rain. The observers must be supplied from the city of Calama, 12 miles away, with water, as well as all other necessities. The sun shines from an unclouded sky on nearly 80 percent of all days. As it is very trying to the nervous system to live in such isolation under constantly cloudless skies, it is necessary to relieve the observers at intervals of 2 or 3 years. Indeed, great loyalty to the objects of the work, excellent ability as observers, much tact in dealing with the people of the vicinity, and conscientious honesty and industry are absolute requirements of the observers for the successful operation

of the station. We have been fortunate that these qualities have so seldom been lacking in our representatives there.

Solar radiation, by being absorbed on black surfaces, is converted into heat. Its intensity is measured by its heating effect. The observatories for measuring the solar constant of radiation have no telescopes. To insure constant temperature surroundings, highly fa-

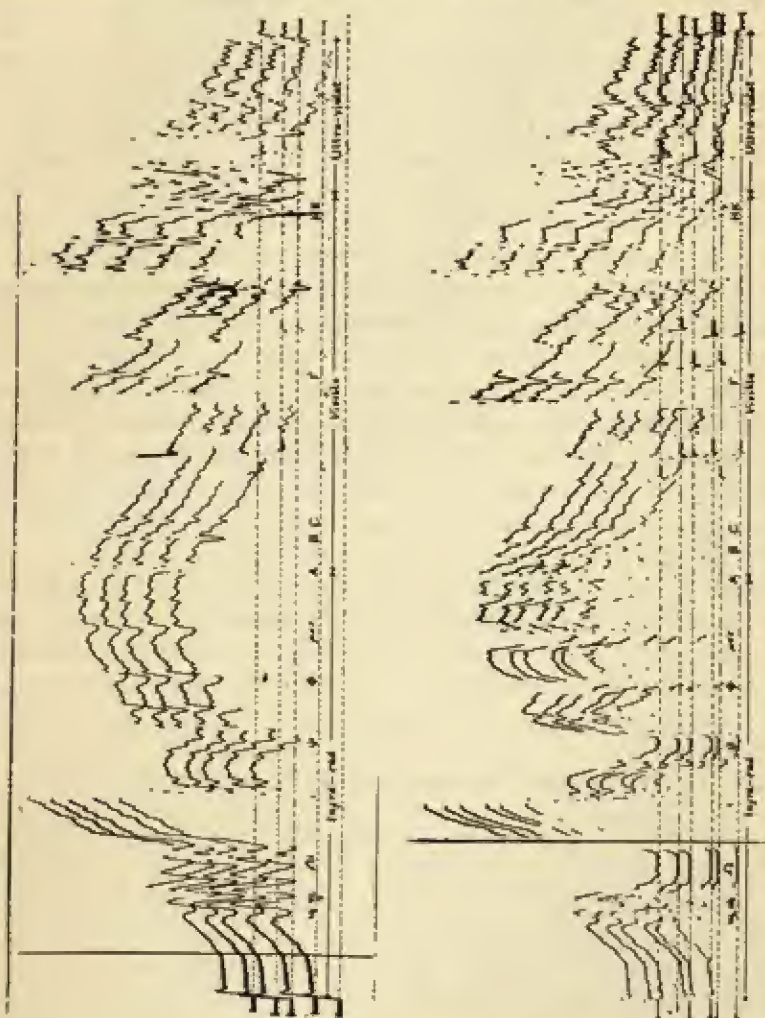


FIGURE 1.—Bolographic energy curves of the solar spectrum made at Montezuma, Chile. The upper set made between early morning and noon of a very dry day; the lower set similarly made on a moist though cloudless day.

vorable to exact measurements, they consist of horizontal tunnels about 10 feet wide and 7 feet high driven into the mountain some 40 feet. We located the tunnels on a south slope in the Northern Hemisphere, and on a north slope in the Southern Hemisphere. Within the tunnel is installed a large prismatic spectroscope, whereby the sun ray reflected into the tunnel by the coelostat outside (shown in pl. 2)

is cast into an intense spectrum, which comes to focus on the bolometer. The bolometer, originally invented about 1880 by Dr. Samuel P. Langley, is an electrical thermometer so sensitive that a change of a millionth of a degree in temperature can be registered. A clockwork causes the solar spectrum to drift slowly across the fine hairlike receiver of the bolometer, and at the same time causes a photographic plate to drop slowly past the tiny spot of light reflected from the mirror of the magnetic-needle system of the sensitive galvanometer connected to the bolometer. Thus is produced in less than 10 minutes a bolograph, or curve showing the distribution of energy of radiation in the spectrum of the sun from far up in the ultraviolet to far down in the infrared. Several such energy curves are taken with appropriate intervals during a morning as the sun rises higher and higher. A group of them is shown in figure 1. Simultaneously with each bolograph the total heating effect of the rays is measured outside the tunnel with an instrument called the pyrheliometer (heat-of-the-sun-meter). Also the altitude of the sun above the horizon is taken simultaneously with the theodolite to indicate the slant thickness of the atmosphere. From this combination of observations it is possible to compute the intensity of the solar radiation as it is outside our atmosphere in free space at mean solar distance. This is the solar constant of radiation.

DAILY VARIATIONS OF THE SOLAR CONSTANT

For 25 years the Smithsonian Institution has been collecting daily measurements of the solar constant, when practicable, with a view to determining the march of the variations of the sun's output of radiation. These fluctuations are small in percentage, rarely exceeding 1 percent. Figure 2 gives the still smaller variations of the monthly mean solar-constant values, 1920-1939. It therefore requires very great accuracy of observing to disclose and evaluate them, hampered as we are by the superincumbent highly variable atmosphere. We are at a disadvantage compared to astronomers who measure variable stars, for they can compare the star investigated with other similar stars nearby, all of which suffer equal percentage losses of light from atmospheric hindrances. The sun is unique and can be compared with nothing near it in the sky. One can only compare an absolute solar measurement of today against an absolute solar measurement of tomorrow, trusting altogether to the accurate determination of atmospheric transmission on each day to make the measurements comparable.

The Institution maintains three solar-constant observatories, two in the Northern and one in the Southern Hemisphere, all on high mountains in desert lands. The following table and summary shows how well the solar-constant daily measurements at great distances apart.

Date and G.M.T.	Station	Air Mass	H ₂ O	Function	Pyth.	Pyth.	S.C.	Grade	Fig. S.C.*
1934									
15	T	250	83 D	50	331	135	81		
16		200	86 D	52	413	121	59		
17		150	113 D	70	465	112	46		
5	K	249	51 E	30	377	167	34		
6		199	54 C	32	442	139	36		
7		150	60 C	33	505	113	30		43
29	K	200	58 C	50	424	159	23		
6		180	57 C	51	454	146	26		43
7		150	58 C	49	502	125	28		20
30	K	200	48 C	42	446	144	50		
8		160	51 C	43	508	124	40		
7		150	54 C	42	516	118	39		44
11	K	200	64 D	65	400	182	32		
6		160	67 D	66	455	166	34		
7		150	68 D	61	500	139	49		39
9	T	249	62 B	48	372	128	37		
13		201	60 B	49	437	112	53		
14		150	56 B	41	530	85	42		
8	K	250	36 C	38	351	196	24		
6		199	54 C	58	425	164	39		40
7		150	51 C	56	500	138	33		53
2	T	220	49 B	28	438	105	47		
13		200	50 B	32	461	101	43		
13		180	48 B	30	482	93	38		
6	K	205	43 B	49	432	147	39		
8		180	42 B	49	488	134	44		
7		150	48 B	42	531	116	43		41
13	M	220	41 A	19	454	95	50		
13		200	40 A	10	480	90	43		
14		150	38 A	8	553	71	41		
13	T	250	161 D	121	264	189	43		
16		200	160 D	123	356	164	40		
17		177	177 D	138	393	132	43		
5	K	249	40 B	45	386	169	34		
6		200	41 B	43	457	141	38		
7		150	42 B	43	524	113	41		43
4	T	220	40 A	7	480	89	57		
13		200	41 A	1	483	82	51		
14		150	36 A	-6	567	64	45		
5	K	250	68 C	62	331	212	16		
6		200	68 C	62	413	178	32		46
7		150	67 C	65	488	144	36		46
9	T	220	45 B	14	457	93	53		
13		200	44 A	8	483	87	55		
14		150	36 A	9	556	72	51		
10	T	250	115 D	96	351	125	41		
16		200	119 D	99	399	111	47		
17		160	122 D	93	455	95	35		
4	K	200	43 B	24	444	167	39		
6		180	40 B	78	484	135	42		
7		150	43 B	68	529	130	40		45
13	M	220	44 A	26	445	100	56		
13		200	44 A	25	476	100	62		
14		150	42 A	20	548	79	42		
15	T	251	86 D	31	372	108	60		
16		200	84 D	25	438	90	51		
17		150	82 D	22	509	75	43		48
2	T	220	36 A	-11	507	88	50		
13		200	35 A	-12	537	85	53		
14		150	36 A	-10	601	67	48		
15	T	250	43 B	-73	412	100	52		
16		200	42 B	-67	475	89	47		
17		160	41 B	-65	531	79	42		
5	K	250	34 C	123	340	279	53		
6		200	36 C	109	419	214	41		
7		150	35 C	119	504	179	30		40
15	T	250	63 C	80	348	182	53		
16		200	60 C	76	418	155	44		
17		150	59 C	60	504	122	45		
5	K	250	62 C	186	307	356	44		
6		200	63 C	183	388	291	41		
7		150	60 C	165	491	218	48		46
9	T	220	44 A	-20	513	84	46		
13		200	44 A	-21	557	78	45		
13		180	41 A	-19	587	75	49		
4	K	200	49 C	117	423	217	44		
8		180	46 C	120	458	199	43		
7		150	51 C	117	521	165	47		47

Date and G.M.T.	Station	Air Mass	H ₂ O	Function	Pyth.	Pyth.	S.C.	Grade	Fig. S.C.*
1934									
10	T	220	10 A	1	499	98	53		
13		200	10 A	-3	512	89	56		
14		150	17 A	-2	600	75	53		
3	K	250	10 A	-23	483	90	46		
6		200	10 A	-27	546	83	43		
7		150	11 A	-21	618	68	43		46
11	T	220	58 B	36	530	81	46		
16		145	58 B	39	530	81	40		
14		140	61 B	37	546	75	52		
16	T	250	31 B	-17	430	97	55		
16		200	30 B	-74	501	84	55		
17		150	29 B	-83	568	70	50		
5	K	249	13 A	-31	475	97	43		
6		199	14 A	-34	532	82	43		50
7		150	13 A	-33	602	69	40		48
12	T	220	55 B	13	441	67	47		
13		200	57 B	17	463	65	51		
14		150	54 B	20	530	70	42		
16	T	250	14 B	-70	430	92	61		
14		200	11 B	-73	497	83	53		
17		160	12 B	-73	545	76	42		
5	K	249	6 A	-21	499	99	59		
6		200	11 A	-29	547	85	46		
7		150	16 A	-32	608	69	51		50
13	T	220	54 B	22	445	100	54		
13		200	53 B	22	467	91	48		
14		150	54 B	23	536	73	46		
16	T	250	19 A	-13	462	94	67		
16		200	21 A	-13	520	82	63		
17		130	22 A	-17	593	66	43		
6	K	200	36 A	36	570	115	53		
6		175	36 A	42	553	100	59		
7		150	36 A	36	579	94	40		49
14	T	220	53 B	22	427	134	54		
13		200	47 B	46	465	117	64		
14		150	48 B	41	540	88	53		
6	K	200	36 B	26	425	118	32		
7		150	31 B	14	556	91	38		50
15	T	252	29 A	11	432	112	52		
13		200	30 A	12	498	94	54		
14		169	27 A	8	572	75	48		51
16	T	220	15 A	-16	514	85	46		
13		200	14 A	-19	537	77	48		
14		150	13 A	-13	613	65	40		
6	K	200	28 B	11	493	107	47		
7		160	31 B	7	517	97	43		40
7		150	20 B	1	563	82	40		46
17	K	250	35 B	-1	429	119	40		
6		200	37 B	2	483	103	48		
7		150	37 B	2	556	85	46		47
10	T	250	27 A	39	468	118	48		
13		200	26 A	39	519	101	43		
14		150	24 A	37	568	91	46		
5	K	250	25 A	-17	440	135	45		
6		200	25 A	-12	504	100	44		
7		150	22 A	-34	578	76	39		45
19	T	250	12 A	-14	510	87	57		
13		200	13 A	-14	536	82	42		
14		150	11 A	-10	607	69	41		
5	K	249	25 A	-37	436	104	37		
6		200	24 A	-53	507	80	43		
7		150	32 A	-45	567	73	40		40
20	T	220	17 A	-14	508	89	48		
13		200	18 A	-12	532	81	54		
14		150	17 A	-1	604	74	50		
16	T	250	98 D	28	371	98	57		
16		200	99 D	27	439	86	57		
17		150	96 D	23	509	73	49		
5	K	250	21 A	-14	451	137	43		
6		200	20 A	-31	510	88	46		
7		150	32 A	-23	566	67	43		51

FIGURE 3.—Facsimile of page 133, volume 6, Annals of the Astrophysical Observatory.

The weighted divergence between stations being 0.0076 calorie, the weighted average departure of one station from the mean solar constant derived from two stations is 0.0038 calorie.

Although it is not fair to Montezuma to suppose that the stations are of equal merit, yet if we make that assumption, and proceed as usual, we find the weighted mean percentage probable accidental error of a single day of observation of the solar constant at one station to be:

$$100 \times 0.0038 \times 0.84 \div 1.94 = 0.164, \text{ or } \frac{1}{6} \text{ of 1 percent.}$$

In volume 6 of the *Annals of the Astrophysical Observatory of the Smithsonian Institution* are contained in table 24 nearly 19,000 measurements of the solar constant observed through the years 1924 to 1939. Several thousand earlier observations of the years 1920 to 1923 are contained in other publications. Figure 3 is a facsimile of a part of page 133 of the *Annals*, which includes the work of September 1934. The several observing stations are distinguished by letters M, K, T, meaning Montezuma, St. Katherine, and Table Mountain. The solar-constant values in columns "S. C." and "Pfd. S. C." are to be understood as prefixed with 1.9. Thus for "50" read "1.950." Using the result of Montezuma and St. Katherine only, which are more accurate than those of Table Mountain, there was apparently an increase in the column "Pfd. S. C." from the 1st to the 5th and from the 10th to the 14th of September, and a decrease from the 14th to the 19th. These changes had an amplitude of the order of 0.5 to 0.9 percent, that is about 0.010 to 0.018 calorie in the solar constant of radiation.

SEQUENCES OF RISING AND OF FALLING SOLAR ACTIVITY

I give in table 2 a summary of nearly 500 of the best supported instances of rise and of fall in the solar constant of radiation selected from table 24 of volume 6 of the *Annals*. The table is arranged by months and will readily be understood by an example. Thus, "January, Rising, 24, 12" means that a case of the solar constant rising for a few days appeared to occur beginning January 12, 1924.

It is of interest and importance to note that the solar variation increases in percentage toward shorter wave lengths. It is six times as great at 3500 Å. in the ultraviolet as in the total solar constant.

EFFECT OF SEQUENCES OF SOLAR CHANGE ON TERRESTRIAL TEMPERATURES

Using this tabulation of the dates whereon sequences of rise and of fall of the solar constant apparently began, I have sought to determine whether such phenomena were associated with special behavior of the

departures from normal temperature and normal barometric pressure at numerous cities. For this purpose I tabulated the departures, let us say of temperature, to illustrate, for 5 days before, and for 14 days after, each date included in table 2. Figure 4 is a facsimile of such a tabulation of temperature departures covering the months of January, February, and March for Washington, D. C. Two curves of temperature departures are shown for each month. One corresponds to the average influence of sequences of rising solar activity, the other to the average influence of sequences of falling solar activity over the years 1924 to 1939. It is to be understood that these curves show temperatures only, not solar constants. One knows only that on the zeroth day of each line of the table a 3- to 4-day sequence of solar changes began. The upper curves of the figure show the average march of temperature departures at Washington in the months of January, February, and March, each associated with 19 or more cases of rising solar sequences, and the lower curves show the average march of temperature departures at Washington in January, February, and March, each associated with from 16 to 21 cases of falling solar sequences.

TABLE 2.—*Dates when sequences of rise and fall of the sun's emission of radiation began*

January		February		March		April	
Rising	Falling	Rising	Falling	Rising	Falling	Rising	Falling
24 12	24 15	24 4	27 13	24 17	24 8	24 7	24 9
18	20	27 27	28 11	23	19	14	18
29	26 1	27 8	29 9	30	25	25 7	23
25 1	9	28 8	30 28	25 18	25 22	15	26 13
26 3	17	17	34 21	25	29	28	29
27 1	28 5	29 2	35 16	26 5	26 30	26 10	27 16
6	14	30 18	21	27 25	28 4	24	28 6
28 9	30	32 5	36 4	28 2	30	27 7	16
28	31 16	34 12	12	34	30 16	22	29 5
31 13	34 4	26	37 8	30 24	31 30	29	32 5
34 20	36 16	35 19	23	30	34 17	28 19	18
35 3	37 6	36 8	38 1	31 22	35 23	29 9	27
10	26	37 2	39 24	28	36 4	30 21	33 4
36 21	38 14	19		32 5	37 20	32 9	13
29				16	37 1	33 10	34 9
37 8				35 3	10	30	17
14				16	38 9	28	35 1
31				36 9	39 16	34 7	19
38 6				37 6		35	27
18				12		14	35 12
26				15		22	39 4
				39 25		36 3	17
						37 8	
						38	
						39	
						16	
						7	
						25	

TABLE 2.—*Dates when sequences of rise and fall of the sun's emission of radiation began—Continued*

May		June		July		August	
Rising	Falling	Rising	Falling	Rising	Falling	Rising	Falling
24 8	24 4	24 12	24 3	24 7	24 22	24 13	24 4
12	10	26 4	20	12	30	23	31
27 10	28 6	26 15	23	26 12	28 22	28 22	26 10
24	20	27 4	27 10	26 5	27 26	29 15	28 5
28 3	29 21	16	29 18	17	28 2	30 24	29 8
9	33 18	28 11	31 1	27 13	10	31 20	21
13	34 5	31 22	32 10	24	26	32 22	30 23
26 1	35 4	32 23	34 4	28 5	29 1	33 15	31 15
30 13	36 13	33 16	35 12	23	12	36	32 4
33 1	37 30	34 8	36 16	29 4	30 1	34 2	34 8
6	37 10	14	37 6	17	33 13	11	22
35 13	38 6	24	22	33 25	34 6	35 8	35 16
38 4	24	35 19	38 5	33 10	35 5	36 9	36 17
16		23	12	19	39 26	21	34
28		37 4	39 10	34 3	37 20	39 20	37 6
39 21		30	21	13	38 20		19
		30 13		22	39 4		
		25		36 13			
				37 6			
				22			
				38 16			
				39 8			

September		October		November		December	
Rising	Falling	Rising	Falling	Rising	Falling	Rising	Falling
24 3	24 11	24 21	24 3	24 28	24 19	24 6	24 1
23	19	29	27	27 4	26 3	25 23	25 7
26 3	26 5	26 7	26 1	19	13	25 24	27 8
27 2	27 8	15	10	29 5	27 24	26 2	24
17	14	24	20	19	29 9	27 4	28 23
19	21	27 4	28	31 3	14	19	29 12
26	29	18	27 10	22	31 23	27	30 7
28 17	29 6	20	21	28	33 18	28 14	31 6
29 23	31 3	28 6	28 8	32 22	34 4	20	17
29 4	9	30 29	21	33 5	35 17	29 15	34 17
12	33 9	31 8	30 4	15	27	31 10	33 20
27	19	18	13	35 15	2	32 27	36 10
30 16	34 6	28	31 2	21	19	33 29	37 10
31 11	14	32 3	33 9	36 5	37 23	34 23	38 29
22	21	33 13	29	13	38 13	35 1	
33 4	35 13	34 11	24 13	27	21	37 4	
13	36 20	17	36 12	37 19		38 7	
28	37 7	28	18	38 8		23	
34 10	21	35 14	37 9				
35 9	28	36 9	23				
22	38 6	36 16	38 5				
36 13	11	37 15					
17		38 9					
37 5							
10							
38 1							
9							
18							
22							
39 4							
11							
21							

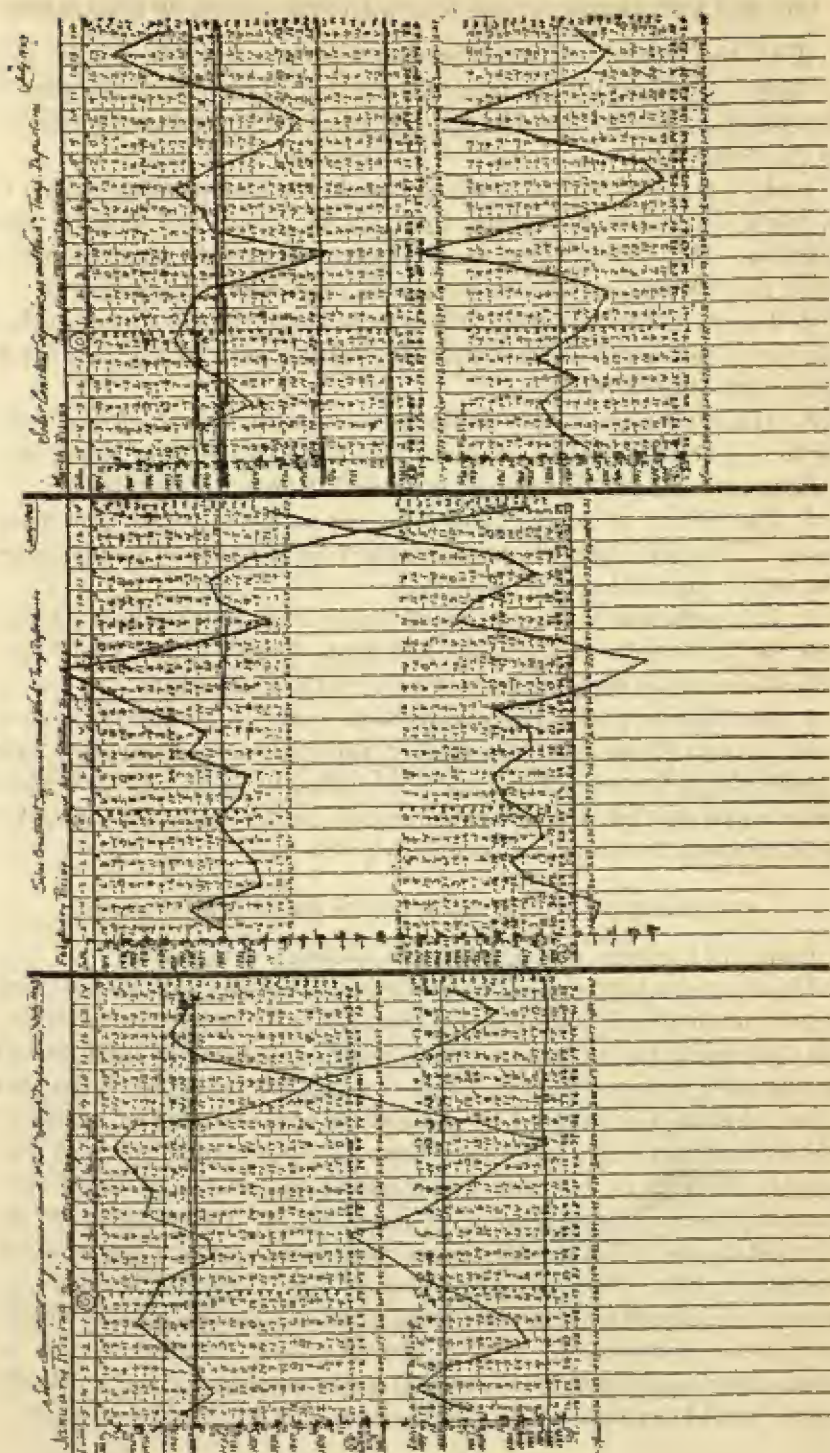


FIGURE 4.—Tabulation of Washington temperature departures for January, February, and March, 1942.

CONTROL OF TEMPERATURES BY SOLAR SEQUENCES OF VARIATION

With this method of investigation clearly set forth, I now give in figures 5 to 7 results for temperatures for all months of the year at Washington, Albany, and Helena, and point out several characteristics of these curves.

1. At every station, and in every month, the temperatures depart in opposite directions, attending, respectively, rising and falling solar activity. Thus comes about an axial symmetry of the pairs of curves such, for instance, as subsists with one's right hand and one's left.

2. The march of the curves differs from month to month, and differs for the same month from station to station, yet the right and left symmetry always prevails.

3. The effects are large. Differences of temperature of the order of 10 degrees Fahrenheit, or more, depend on whether a rising or a falling sequence of solar activity preceded them many days before.

4. The effects of solar changes on temperature persist for many days. They may surely be traced from 3 days before to 14 days after the zeroth day of the solar sequence.

5. The coefficient of correlation of these curves for the three stations and the 12 months of the year, and from 3 days before to 14 days after the solar change, is found to be $r = -61.2 \pm 1.7$ percent.

6. Since far-separated cities respond in a similar manner to the common system of dates given in table 2, this system of dates must have a cosmic significance. The system of dates, in other words, betrays an extra-terrestrial selection, harmonious to the claim that on these dates changes in radiation occurred in the sun.

SUPPORTING EVIDENCES OF SOLAR WEATHER CONTROL

Doubters, however, may argue to the contrary as follows:

The changes claimed in solar radiation, they may say, are so small in percentage that it is improbable that observation, however accurate, can distinguish them from accidental errors, and from the influences of atmospheric sources of error. May it not more probably be that the series of dates was selected by chance? They were, indeed, dates on which, in the average, large variations of temperature followed over periods of 17 days, but this was merely accidental. It would then naturally occur that sequences of dates closely following those attributed to rising solar radiation would show opposite temperature tendencies, since whatever goes up must come down. That far-separated cities would react to the same systems of dates, though not identically, is not surprising. For, as is well known, weather travels in waves from west toward east, so that a disturbance arrived at Washington would have passed by stations to the west some days earlier.

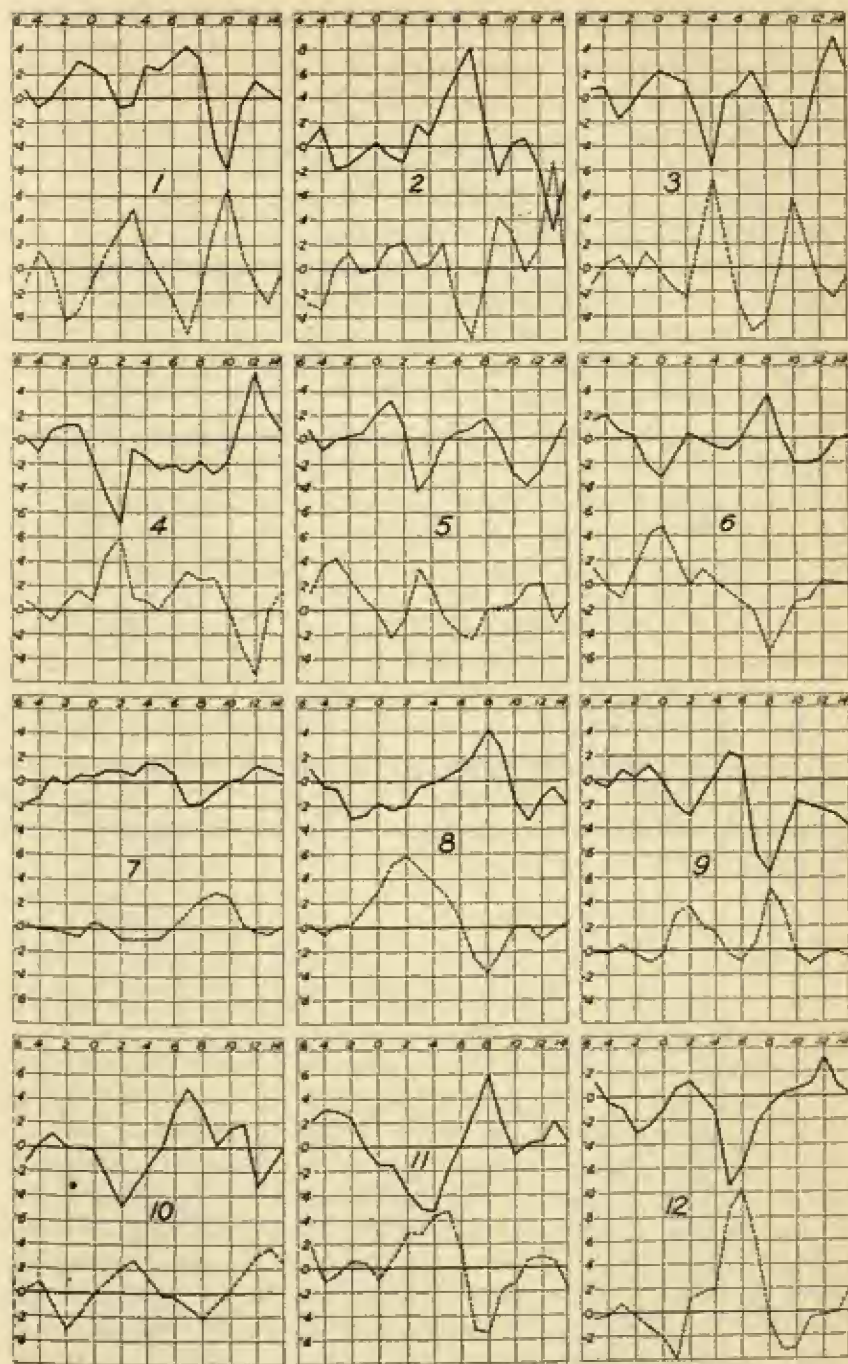


FIGURE 5.—Average marches of temperature departures, Fahrenheit, at Washington, D. C., accompanying sequences of variation of the solar constant, January to December.

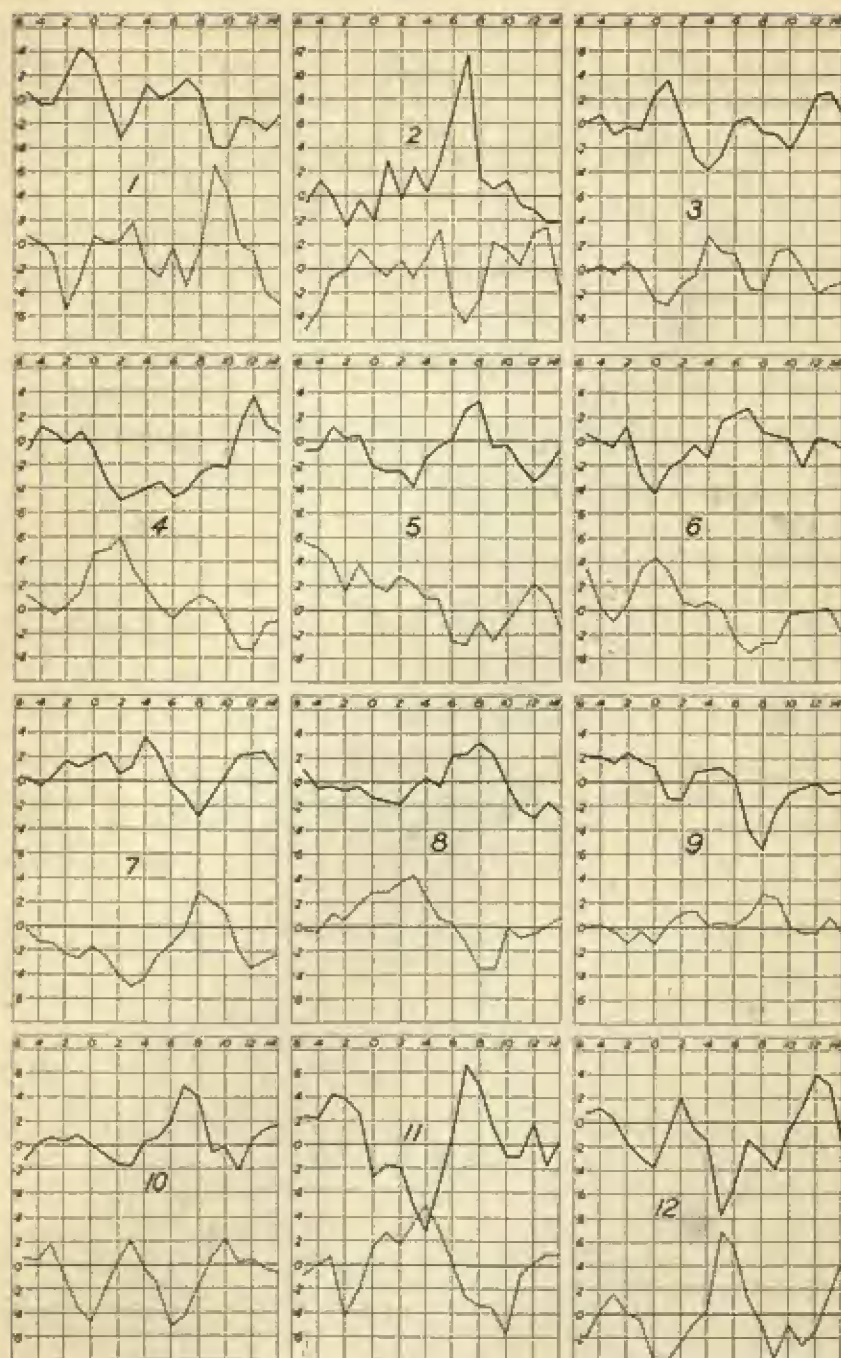


FIGURE 6.—Average marches of temperature departures, Fahrenheit, at Albany, N. Y., accompanying sequences of variation of the solar constant, January to December.

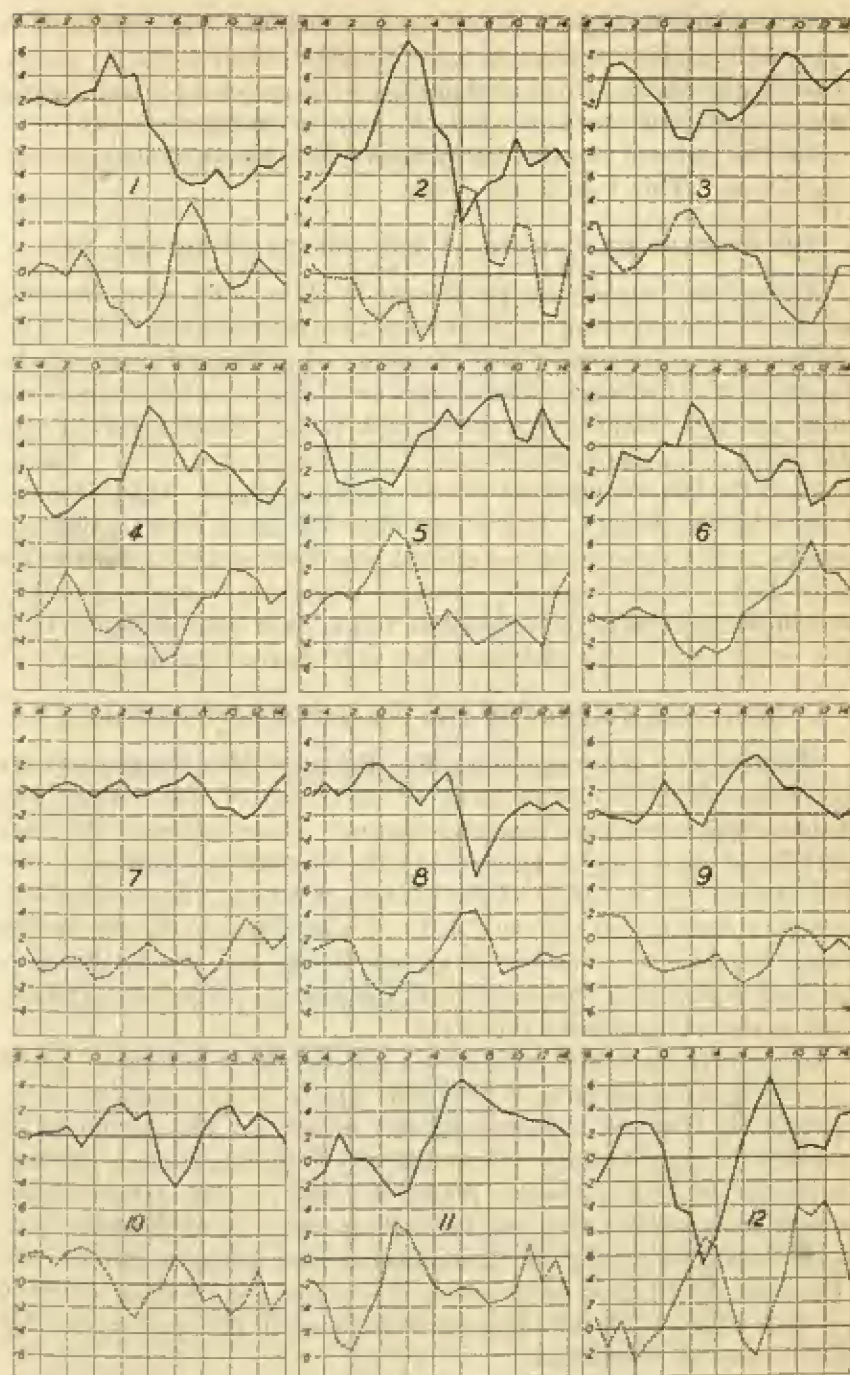


FIGURE 7.—Average marches of temperature departures, Fahrenheit, at Helena, Mont., accompanying sequences of variation of the solar constant, January to December.

These plausible arguments may be confuted, but it is doubtful if so complex a proposition could be made altogether clear to the lay reader. The simpler course is to show that these same marches of temperature, at these same cities, are associated with another common system of dates in another series of years, which system of dates has an undoubted solar connection. This I shall now show.

THE SPECTROHELIOGRAPH AT THE OBSERVATORIO DEL EBRO

The eminent astronomer, Dr. George E. Hale, in his youth invented the beautiful instrument which he named the spectroheliograph. This device photographs the clouds of vapors of individual chemical elements, such as hydrogen, helium, iron, or calcium which float above the sun's surface. Hale's spectroheliograph found instant favor all over the world, and many observatories were equipped with it. Among them is the Observatorio del Ebro in northern Spain, which is maintained by the Jesuits. Every available day from 1910 to 1937 the monks at Ebro photographed the calcium clouds on the solar surface with their spectroheliograph. And not only did they observe, but they measured the areas of these clouds as well as their mean distances from the center of the sun's disk, and they published all the measures.

CHARACTER FIGURES OF THE SOLAR-FLOCCULUS ACTIVITY

With the help of my assistants, Mrs. Bond and Miss Simpson, I have used these Spanish measurements of every day of observation from 1910 to 1937 to compute character figures. These represent the solar activity of a given day as measured by the summation, according to certain weights, of the areas of the calcium clouds, or "flocculi," photographed that day on the sun's disk. These character figures having been assembled by months in 12 groups, it was seen at once that they showed sequences of rise and of fall, for intervals of a few days each, just as the solar-constant values do.

Going over the tables with care, I selected dates in each of the 12 months in the years from 1910 to 1937 when the best examples of sequences of rise and sequences of fall occurred. The period of 28 years is so long that there was no difficulty in finding enough excellent sequences without including doubtful cases. I thus tabulated the zeroth dates of the rising and the falling sequences of flocculus character figures for each of the 12 months covering the years 1910 to 1937. Then the Washington temperature departures from 5 days before to 14 days after each zeroth date were tabulated in the same way as for solar-constant correlation.

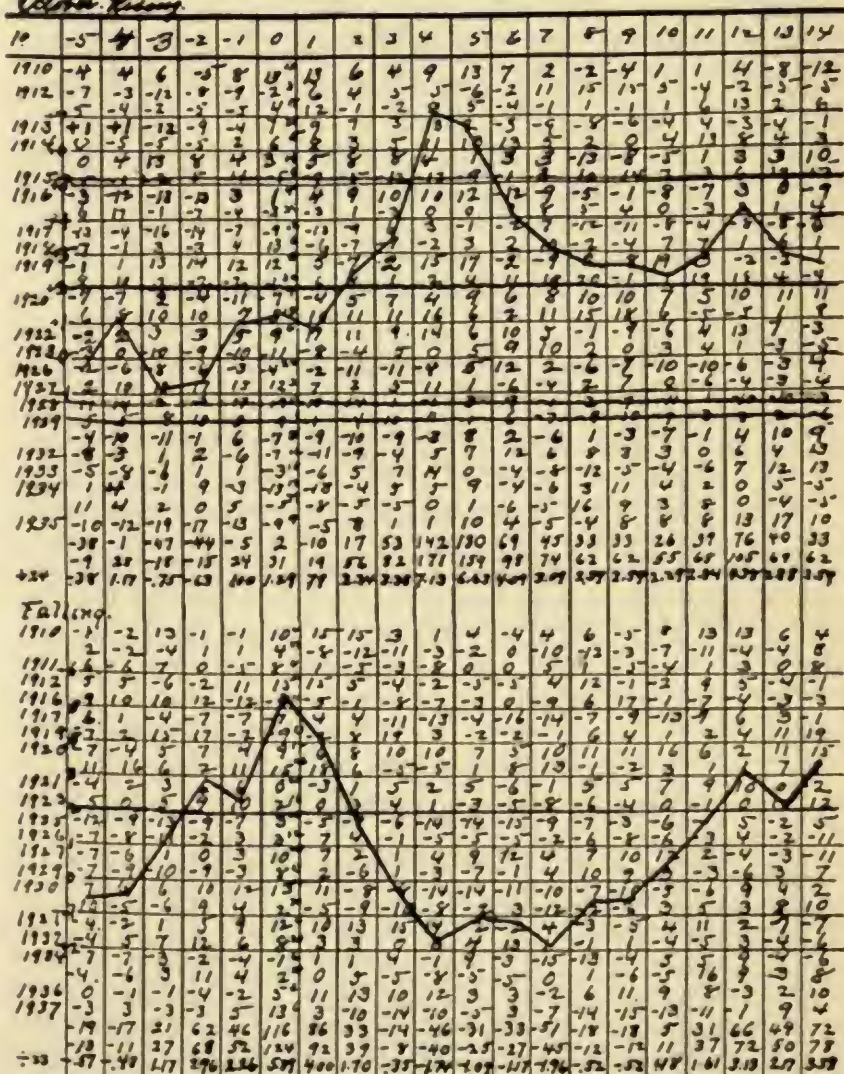
CONFIRMATION OF SOLAR-CONSTANT RESULTS BY WORK AT EBRO

Mean values were taken, and often in these tabulations more than 30 cases entered in each mean. I show in figure 8 a computation and

Obs 10.7.5.31 Night and Day Temp. departures.

Oct 1913.

October Rising.



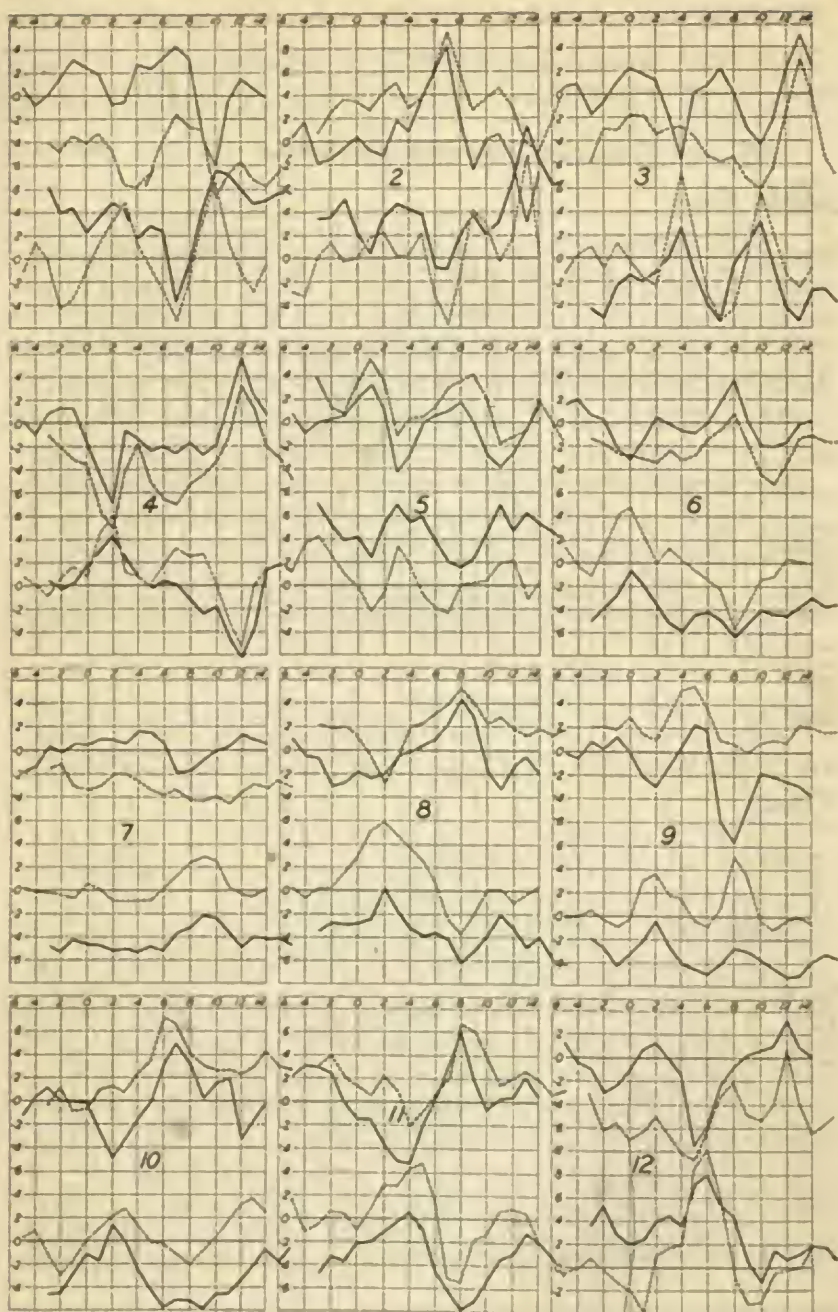


FIGURE 9.—Average marches of temperature departure, Fahrenheit, at Washington, D. C., accompanying sequences of solar change (a) of the solar constant in years 1924 to 1939; (b) of character figures for solar calcium flocculi in years 1910 to 1937, for months January to December. Ordinates are temperature departures; abscissae are days from beginning of solar-constant sequence. Flocculi area curves are displaced 2 days to right.

partures at Washington for the 12 months, as associated both with solar-constant sequences and with flocculus character-figure sequences.

It is at once apparent that similar curves of temperature resulted, but that the curves based on flocculus character figures show 2 days' lag in phase compared to the curves based on solar constants. The two kinds of solar change, in other words, are not exactly simultaneous. The reader will see in the diagram that for comparison purposes the flocculus temperature curves are all moved to the right 2 days with respect to the solar-constant-temperature curves. This phase difference allowed for, the correlation coefficient between solar-constant and flocculus temperature curves for Washington is $r=59.7 \pm 1.9$ per cent. It will be noted that the two systems of dates used for the two determinations have almost nothing in common. They are spread over two different series of years, one interval 1910 to 1937, the other 1924 to 1939. Owing to differences in days lost for cloudiness in Spain and northern Chile, only a few of the dates in the two intervals are adjacent. In short, in method, in the years observed, and in detail, the two determinations have only this in common: both purport to show the influence of changes of solar activity on Washington temperature. One of the methods uses photographic phenomena universally admitted to be solar. Since the results of the two methods are well-nigh identical, how can critics longer reasonably deny that in the basis of the other method (the solar-constant variation) is also a truly veridical solar phenomenon?

I therefore claim for the Smithsonian Institution the discovery and measurement of variations of the solar constant of radiation, and the proof that these solar variations are major factors in the control of terrestrial temperatures.

SOLAR SEQUENCES AND BAROMETRIC PRESSURE

We have investigated also the dependence of barometric pressure on the solar variations tabulated in table 2. I will not enter extensively into this branch of the subject, nor show further examples of the temperature effects, because I have much else to present in this lecture. I will only draw attention to the march of barometric pressure at Denver and Ebro (figs. 10, 11) for the 12 months, as associated with rising and falling sequences of solar-constant changes. It will be seen that the curves, while not so consistent as the temperature curves, already shown, still generally display that right-and-left symmetry which has been referred to in temperature.

POSSIBILITIES OF DETAILED LONG-RANGE FORECASTING

I now turn to the question whether these solar variations, since individually they apparently produce major changes of weather for inter-

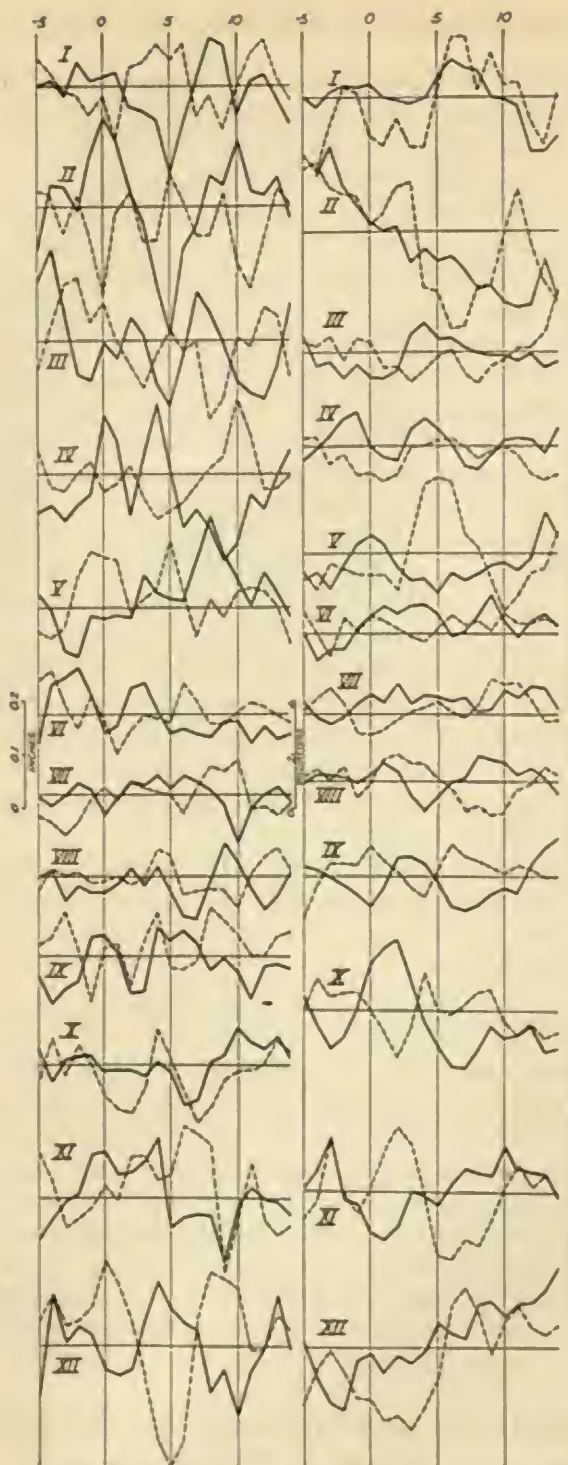


FIGURE 10.

FIGURE 11.

FIGURES 10 AND 11.—Barometric departures associated with sequences of solar-constant variation for 12 months, January to December, at Denver, Colo. (fig. 10) and Observatory of Ebro, Spain (fig. 11). Full curves, rising sequences; dotted curves, falling sequences.

vals of nearly 20 days, may give hope that a method of forecasting for many days in advance may be evolved therefrom. I have, indeed, made a preliminary test of this possibility.

It will be apparent that after computing basic curves of the temperature effects of solar variation for a given station, it may be assumed that when a sequence of rise of the solar constant is described in the daily observations, one may write down in a column for some 2 weeks thereafter the departures in temperature expected to follow this sequence of rising solar activity. As other sequences occur, some rising, some falling, other parallel columns of expected temperature departures are written down on the proper dates, appropriate to each.

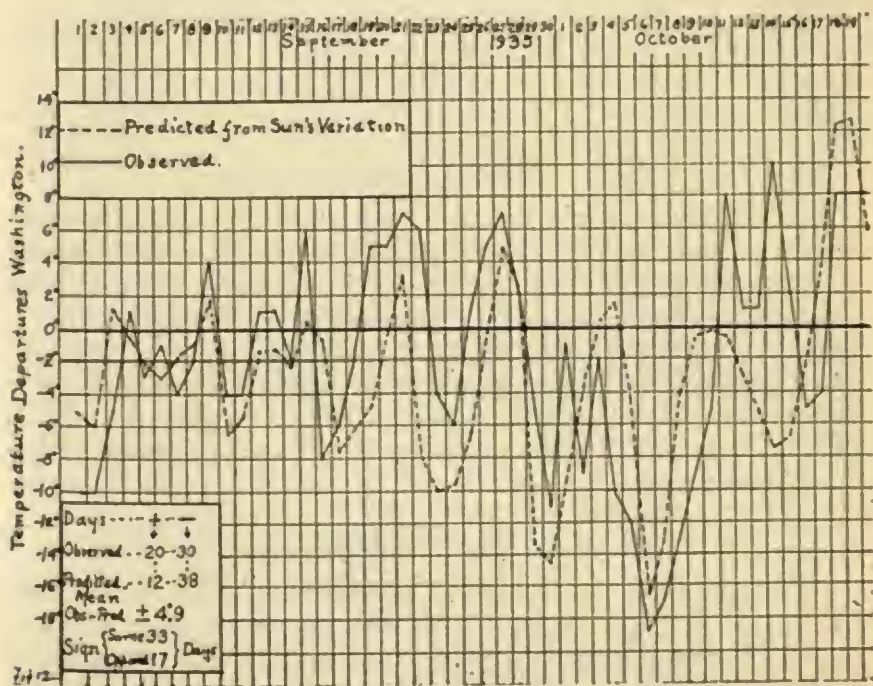


FIGURE 12.—Forecast and verification of Washington temperature departures.

By the summation of all of these columns day by day, one finds an expression of the total influence of solar variation. This summation may go on continuously, always for as much as 10 days, in advance of the calendar. Figure 12 gives such a summation for September and October 1935, prepared from solar-constant basic curves for Washington and Ebro dates.

Unfortunately the solar-constant daily values of first-class quality are too scattered as yet, with only our two first-class stations observing. However, I have found several months in the long record of calcium-flocculi measurements kept at Ebro when the breaks were so rare

that a fair estimate of the dates of changes in solar activity could be made. With allowance made for the difference of 2 days in phase, the basic curves used were those derived for Washington temperatures from solar-constant work. The general result was as summarized below:

	<i>Days</i>	
Total predicted.....	201	
Observed and predicted, same sign.....	139	
Observed and predicted, opposite sign.....	62	
Observed departures: Plus 65, minus 136.		
Predicted departures: Plus 64, minus 137.		
	<i>Num- bers</i>	<i>Percent- ages</i>
Differences: 0° to 2°.....	66	32.7
3° to 4°.....	43	21.3
5° to 6°.....	32	15.8
General 7° to 10°.....	33	16.3
mean= 11° to 15°.....	20	10.0
5°.35. Over 15°.....	8	4.0

Correlation coefficient=56.9±3.2 percent.

This preliminary test, which is a forecast based on solar data alone, gives some ground for hope that with more accurate and continuous observation of solar-constant values, when these are obtained every single day, such solar forecasts, supplemented and corrected by the extensive knowledge of terrestrial influences now available to meteorologists, may in that combination greatly promote longer-range weather forecasting. Since solar changes are a major weather factor it is difficult to see how long-range weather forecasts can be made if they are neglected as always heretofore.

THE 27-DAY PERIOD IN WASHINGTON PRECIPITATION

I now present a curious result of investigation of the sunspot rotation period of 27 days in connection with the precipitation at Washington. In the year 1942 I collected values of the daily precipitation at Washington from 1924 to 1941. These values I arranged in cycles of 27 days. Since 27 such cycles fill 2 complete years, lacking 1 or 2 days depending on leap year, it was convenient to tabulate the values in nine 2-year tables, and take the mean values for each of them.

I was immediately struck by the circumstance that for the mean of every 2-year tabulation, the 11th day of the cycle in the earlier years and the 12th day of the cycle in the later years was from 2 to 3 times as rich in precipitation as the 6th and 7th day. The cycle, whose true period seems to be 27.0074 days, was always taken in the phase as of January 1-27, 1924. On taking the general mean of 243 cycles, the characteristic of high values about the 12th day was very marked, but other parts of the cycle also were conspicuous as high or as low in

precipitation. I then divided the data into three sections representative of dry years, 54 cycles; intermediate, 108 cycles; wet years, 81 cycles. The results are given in figure 13.

A VERIFIED PREDICTION ONE YEAR IN ADVANCE

In March 1943 I informed the Chief of the Weather Bureau that on a certain list of dates the average daily precipitation would be higher than on the remaining dates of the year. I recently tabulated the results: Using curve 3, applicable to years of intermediate precipitation, the selected dates of 1943 were expected to show 166 times the average



FIGURE 13.—27.0074-day period in Washington precipitation. Curve 1, general mean, 243 cycles; curve 2, dry years, 54 cycles; curve 3, intermediate, 108 cycles; curve 4, wet years, 81 cycles.

rainfall of the nonselected dates. The actual ratio, for the 175 selected dates compared to 191 nonselected (the work included December 31, 1942) was 1.58.² The 27-day cycle has continued so consistently for 20 years at Washington that one is inclined to think it may be trusted to hold for some years to come.

MONTHLY MEAN SOLAR CONSTANTS

We will now consider monthly mean values of the solar constant of radiation, the variations they disclose, the periodicities found

² I might add that the 2 days of large rainfall in January 1944 fell on selected dates also.

therein, and the effects of these long-term solar variations on weather. Figure 2 gives the monthly mean solar-constant values from 1920 to 1939. The curve shows fluctuations which appear to be wholly irregular. If one asks, are these fluctuations really true changes in solar radiation, their very magnitudes give a strong presumption that they are so. For in the comparison of daily values given above it was shown that the probable error of the result of a single day of observation from one station is but $\frac{1}{6}$ of 1 percent. A monthly mean includes from 30 to 80 such values. Hence, recalling that the probable error of a mean is the probable error of the individual value divided by the square root of the number of values entering into the mean, we see that the probable error of a monthly mean value is from a thirtieth to a fiftieth of 1 percent. Yet the fluctuations in figure 2 range up to more than 1 percent. Hence probably many of them are veridical.

PERIODICITIES IN SOLAR VARIATION

Although seemingly irregular, the march of solar variation shown in curve A, figure 2, like the characteristic voice of the violin or of the trumpet, comprises a long wave with many simultaneously active shorter waves related to it by simple ratios. However in the solar variation the simple relationships appear to be only approximate, not quite exact, to the master cycle of $22\frac{3}{4}$ years, or 273 months. Nevertheless it is very interesting that this master period, so nearly a least common multiple of 13 shorter ones, is approximately double the well-known sunspot cycle of $11\frac{1}{2}$ years, and thus equal to Hale's period of magnetic changes in sunspots. Strangely enough, though, the sunspot cycle does not appear among the 13 submultiples of the solar-constant master period, for no evidence of this $11\frac{1}{2}$ -year period can be found in the variation of the solar constant.²⁴

Here are the observed periods, and their approximate relationship to 273 months:

1	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{6}$	$\frac{1}{4}$	$\frac{1}{8}$
273	91	68	54	45 $\frac{1}{4}$	39 $\frac{1}{2}$	34
$\frac{1}{6}$	$\frac{1}{11}$	$\frac{1}{13}$	$\frac{1}{23}$	$\frac{1}{24}$	$\frac{1}{28}$	$\frac{1}{31}$
30 $\frac{1}{2}$	25 $\frac{1}{4}$	21	11.87	11.20	9.79	8.12

Curve B of figure 2 is made up by adding together the separate influences of these 14 periodicities as they were determined from curve A by numerical analysis. The fit of the observed curve by the synthetic one is so good that in figure 14 of the *Annals*, published several years ago, the curve B was carried on as a prophecy of solar variation to the end of 1945. Four years of observation have become available from Montezuma station, though only in a provisional, not the final, reduction. Figure 14 shows a comparison between the prophesied and actually observed solar variation. Not

²⁴ See, however, L. B. Aldrich, *Smithsonian Misc. Coll.*, vol. 104, No. 12, July 2, 1945.

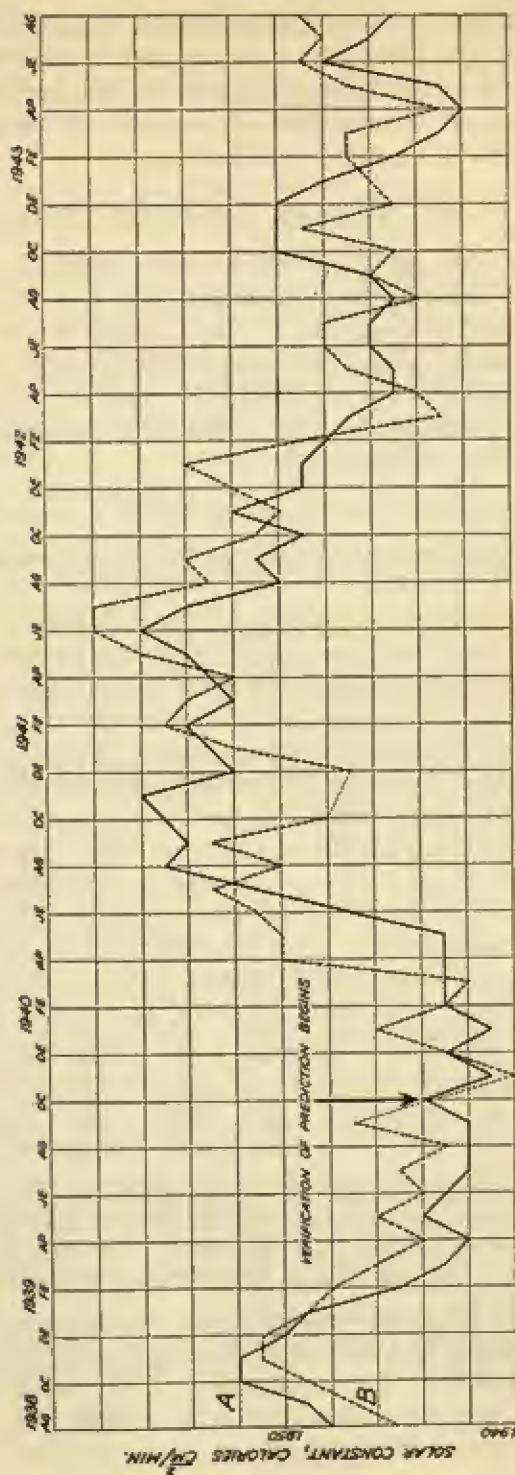


FIGURE 14.—The solar constant of radiation. A, predicted; B, observed.

only in general, but in many details, there is much similarity. We await with very great interest the crucial test to come in the latter part of 1944 and 1945. If the prophecy is then verified, we may expect, as I pointed out occurred about 1922-23,³ unusual weather conditions in 1945-46.

EFFECT OF LONGER SOLAR VARIATIONS ON WEATHER

Among the shorter periods found in solar variation, as indicated by Smithsonian solar-constant measures, are periods of approximately 8, $9\frac{3}{4}$, and $11\frac{1}{4}$ months. I have sought to determine how these and the longer periods of solar variation affect temperature and precipitation in many cities. To fix ideas I give a tabulation (tables 3 and 4) for 8, $9\frac{3}{4}$, and $11\frac{1}{4}$ months at Copenhagen to show how these influences are examined.⁴

TABLE 3.—Copenhagen temperature departures, smoothed. Test of 8-month period

[Values of January to August only. Unit: 1/10 degree C.; for means, 1/100 degree C.]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
1800.....	-19	-17	-47	33	29	-12	-4	15
1802.....	-15	-11	22	10	-15	-17	-33	6
1804.....	18	-21	-25	-8	11	3	5	11
1806.....	17	19	-4	-19	8	-20	-15	9
1808.....	8	-11	-19	-17	9	9	24	26
1810.....	1	-5	-2	-16	-27	-4	8	6
1812.....	-1	13	-18	-32	-14	-4	-21	2
1814.....	-53	-53	-29	4	-30	-15	10	-2
1816.....	4	-22	-4	-6	-27	-15	2	-14
1818.....	14	15	20	-21	-3	11	14	-2
1820.....	-32	1	-4	12	0	-15	-7	-3
Mean.....	-53	-64	-100	-39	-54	-72	-15	+49

TABLE OF MEANS

1800 to 1820.....	-53	-64	-100	-39	-54	-72	-15	+49
1822 to 1842.....	-71	-6	105	42	8	15	-4	18
1844 to 1864.....	-76	4	-17	-1	-9	-11	-52	-30
1866 to 1886.....	127	115	44	85	-27	4	35	24
1888 to 1908.....	123	59	25	1	-1	17	-25	-64
1910 to 1930.....	74	108	133	96	58	-59	46	-16

The maximum appears to shift 11 months and the minimum 19 months to the right in 110 years. With such large shifts one cannot exactly determine the proper correction to the period with one trial. These shifts however indicate: By the maximum, $\frac{11 \times 8}{100 \times 12} = \frac{1}{18}$ month; by the minimum, $\frac{19 \times 8}{110 \times 12} = \frac{1}{9}$ month. Further trials led us to fix on the correction $\frac{1}{36}$ month, and to prefer the period $8\frac{1}{36}$ months.

³ Proc. Nat. Acad. Sci., vol. 9, No. 6, June 1923.

⁴ In this publication I give only the tabulation for the 8-month period, and its correction to $8\frac{1}{36}$ months for Copenhagen. Others were shown at the lecture.

TABLE 4.—*Copenhagen temperature departures, smoothed. Test of 8½-month period*
 [Values of all months employed. Means only given. Unit: 1/100 degree C. throughout.]

Years	November-December beginnings							
1798 to 1833.....	-19	24	21	7	84	11	18	-6
1833 to 1868.....	-153	-55	-48	-4	-10	-75	-41	-66
1868 to 1903.....	20	85	88	103	33	77	-23	-3
1903 to 1937.....	-102	20	36	44	29	-4	-5	-20
1798 to 1937.....	-79	22	29	65	41	3	-15	-29
1798 to 1937								
Nov. and Dec.....	-79	22	29	65	41	3	-15	-29
Jan. and Feb.....	4	-3	-32	34	59	-1	-7	-6
Mar. and Apr.....	-29	-29	-64	-19	-56	-39	-29	15
May and June.....	-1	45	44	4	-12	24	33	46
July and Aug.....	29	38	-24	-1	-12	16	8	-31
Sept. and Oct.....	24	32	52	6	5	18	40	42

That there is here no progressive secular displacement of the phases of means of groups beginning at a constant season of the year, is shown by the extended table for November-December. But groups beginning at different seasons of the year do show displacement of phases with respect to one another.

I soon found that while there seemed to be some tendency to periodicities in weather corresponding to the solar changes, these weather periodicities, unlike their solar counterparts, fluctuated in phase. It occurred to me, however, that this instability of phase is but a natural seasonal effect for the periods of shorter duration like 8, 9½, or 11¼ months. For the phase of terrestrial response to a solar cause must evidently depend on local terrestrial circumstances. For instance, there will be a longer lag with stations under oceanic control than for those in cloudless deserts. Pursuing this thought it occurred to me that the phase, for example, of an 8-month period of response to solar change in weather must be different if the solar cause occurs in summer than if it occurs in winter. I investigated this idea for several periods and many stations. Figure 15 shows that my surmise was a correct one.

Hence terrestrial responses to solar periods of moderate lengths should be expected to be in the same phases only when the solar causes occur at the same time of the year. If a solar period of exactly 8 months existed, we must compare its terrestrial effects 2 years apart, for then their solar causes would occur exactly at the same seasons of the year.

I will not delay to show exactly how we make use of the calendar to eliminate seasonal phase changes, but will content myself with showing for three stations, Copenhagen, Vienna, and New Haven (see tables 3 and 4), that when this complication is properly allowed for, and when the exact length of the solar period is determined, the terrestrial response is proved to be exactly in phase from the year 1700 to the present

time. Figure 16 shows how necessary it is in such a long term of years to select the exact period. Using 8 months there is but small amplitude, even when seasonal influences are eliminated, but with

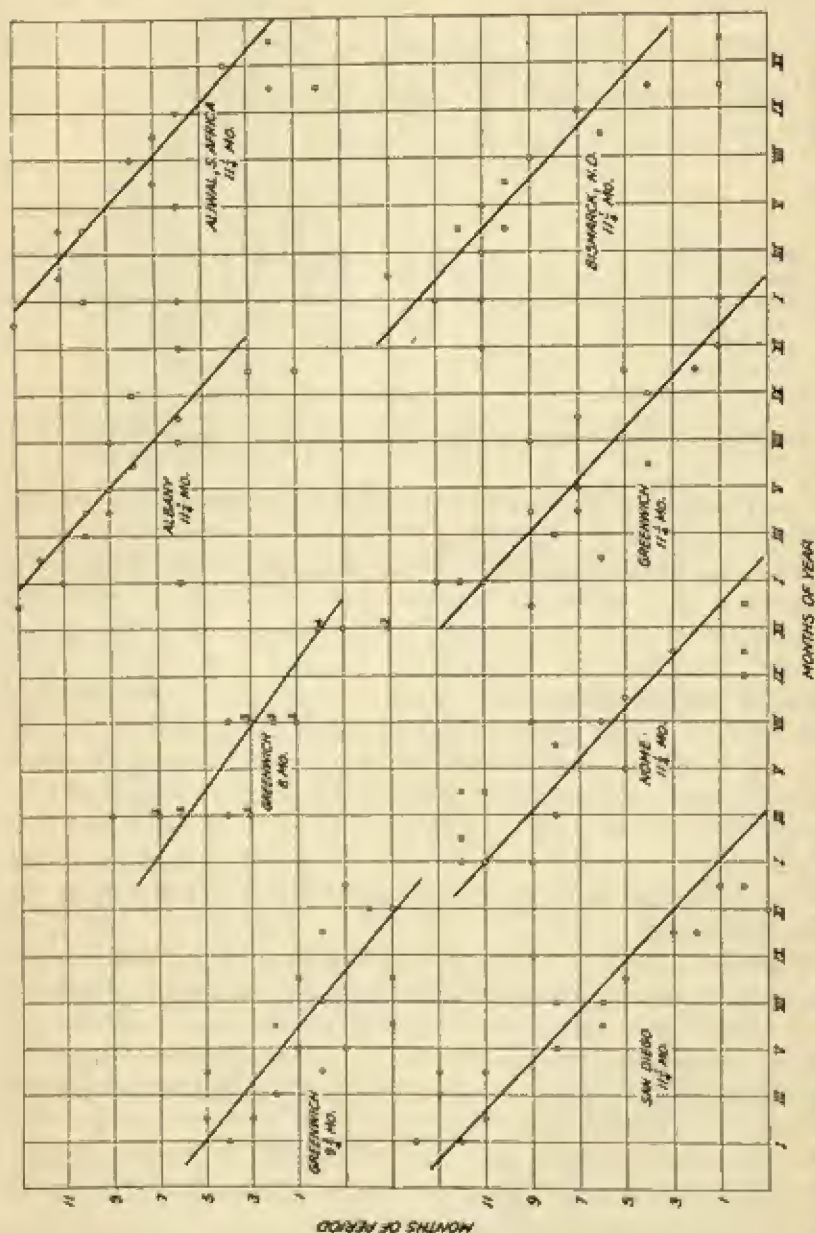


FIGURE 15.—Phase relations of periodicities in terrestrial responses to solar variations, depending on seasons of the year.

8 1/3 months all three stations show a strong periodicity, with amplitudes of 1°3 C., 1°1 C., and 1°3 F., respectively, over nearly a century and a half. In this way we have been able, by using tempera-

ture records at terrestrial stations, to obtain more exact periods of the solar changes than could be fixed by solar-constant measurements extending only since the year 1920.

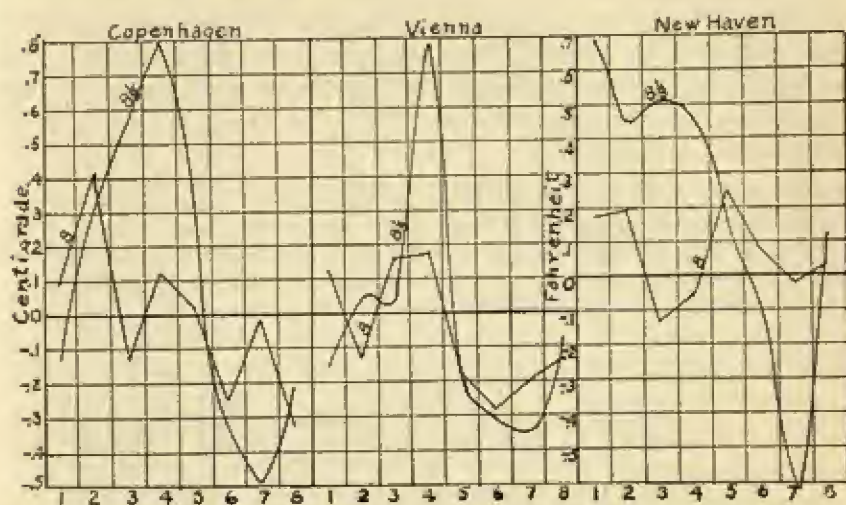


FIGURE 16.—A periodicity of $8\frac{1}{2}$ months in temperatures at Copenhagen, Vienna, and New Haven, Conn., since the year 1700. Seasonal phase disturbances are excluded.

PERIODICITIES IN WEATHER

Since the 14 periods* simultaneously active in solar variation are approximately aliquot parts of 273 months, we may anticipate that the many weather features occurring at a station in this interval of nearly 23 years will tend to repeat with some measure of similarity in successive 23-year cycles. Experience shows that this influence is more effective at some stations than at others. Figure 17 shows what has happened at one of the most responsive stations, Peoria, Ill. It will be seen that especially in the last half of the cycles the tendency of features to repeat in Peoria precipitation is quite marked. Two attempts to forecast, made in 1934 and in 1938, are shown by heavy dotted lines, and by light full lines, respectively, in figure 17.

I have made use of this 273-month master period to predict precipitation for some years in advance at a number of limited regions of the United States. I reduced the prediction to a purely routine computation, and used the percentages of normal precipitation smoothed by 5-month consecutive means. Thus for March

*To them must be added the sunspot cycle of approximately $\frac{273}{2}$ months. For though it does not appear in variations of the solar constant, the ionic bombardment of the earth from sunspots is not negligible as a weather factor.

use the summation $\frac{\text{Jan.} + \text{Feb.} + \text{Mar.} + \text{Apr.} + \text{May}}{5}$, and for April, $\frac{\text{Feb.} + \text{Mar.} + \text{Apr.} + \text{May} + \text{June}}{5}$, etc. Then for the expected smoothed

percentage precipitation value for January of a future year, take the smoothed value for April 46 years previously, plus the smoothed value for February 23 years previously, and divide by 2. This simple rule works very well for some stations. Thus for Eastport, Maine, from 1935 to 1942, inclusive:

For 96 months, average observed minus predicted.....	±16 percent.
Number observed and predicted on same side of 100 percent.....	78
Number observed and predicted on opposite sides of 100 percent.....	18
Number, though observed and predicted on opposite sides of 100 percent, their difference observed minus predicted, less than ±16 percent.....	6

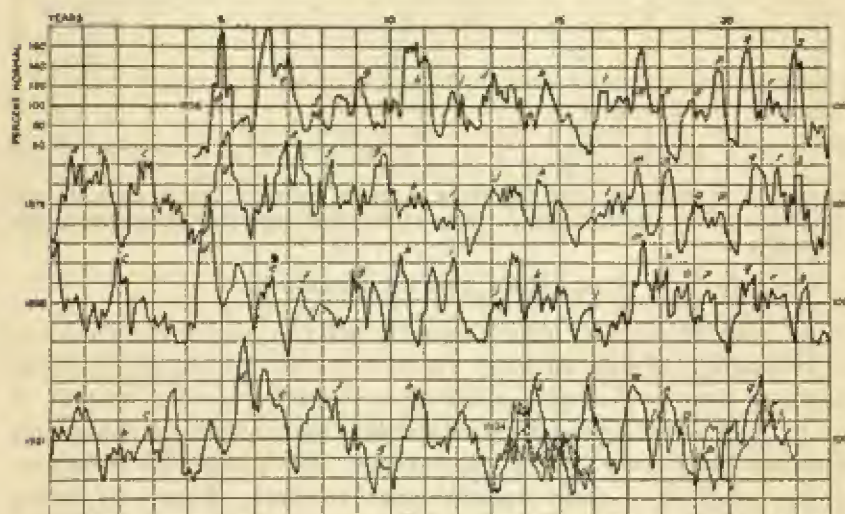


FIGURE 17.—Precipitation at Peoria, Ill., smoothed by 5-month running means, arranged in 23-year cycles. Letters represent similar features in successive cycles. Forecasts (dotted line, from 1934; thin line, from 1938) made by consideration of preceding cycles.

From these figures one may fairly claim that of 96 months predicted 84 were useful predictions, or a measure of success of 87 percent. For 12 New England stations similarly evaluated, 807 were useful, 345 unsatisfactory months' predictions.

Several years ago, at the request of a Colonel of Engineers I made in this way from records of 10 stations a prediction for 3 months of the expected precipitation in the Tennessee Valley region. My prediction of precipitation was 84 to 87 percent normal. The event was 87 percent normal.

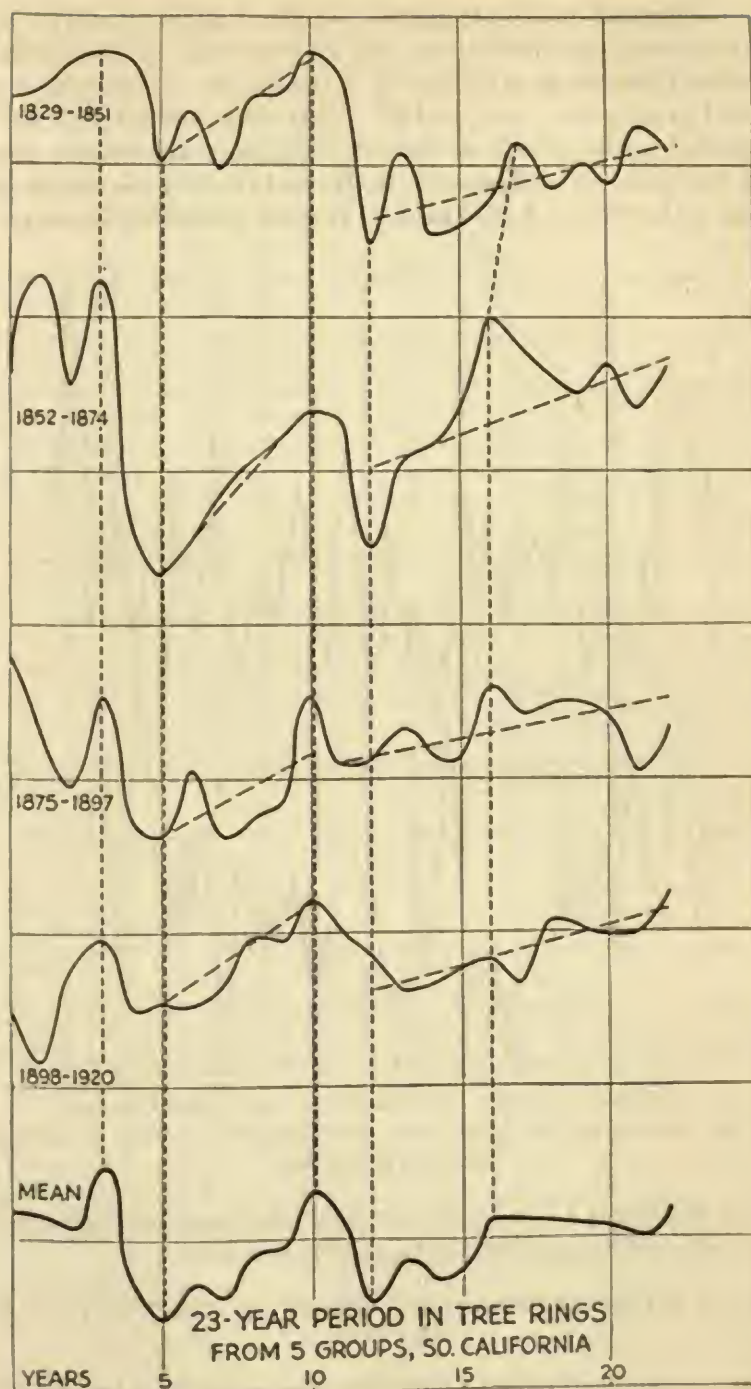


FIGURE 18.—The 23-year period as found in the thickness of tree rings from five southern California groups, 1829 to 1920.

The double and quadruple master periods of about 46 and 91 years seem even more prominent than the 23-year cycle in precipitation. In further illustration of the effects of the 23-, 46-, and 91-year periodicities I give figures 18, 19, and 20. They show, respectively, the 23-year period in the growth of trees in California, the 46-year period in the precipitation at Bismarck, N. D., and the 23-, 46-, and 91-year periods in the level of Lake Huron. It seems probable that large de-

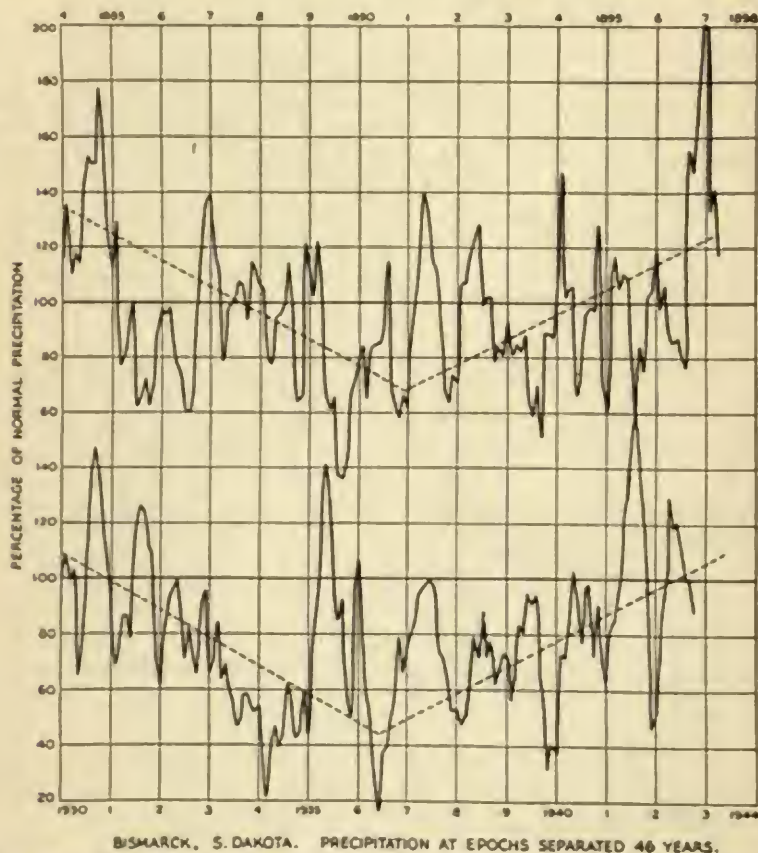


FIGURE 19.—The dotted line in the lower curve, from 1937 to 1943, was drawn in 1937 as a prediction.

clines in the Great Lakes levels, accompanying great droughts in the Northwest, will begin about the years 1975 and 2020.

THE 14 SOLAR PERIODICITIES REFLECTED INDIVIDUALLY IN WEATHER

There is another method of making long-range weather forecasts based on solar variation. With strict attention to the seasonal influences on phase already referred to, one may compute from monthly

weather records of the past what are the effects of each of the 14 solar periodicities on temperature and on rainfall for any desired station. Then, assuming that these influences will continue with the same effects in future, and still paying close attention to the seasonal changes of phase, one may add together all these effects, and also the sunspot-cycle effect, similarly determined from records of the past, and thus prepare a forecast for several years in the future.

With the aid of my assistant, Miss McCandlish, I have made such forecasts of temperature and precipitation for several cities in the

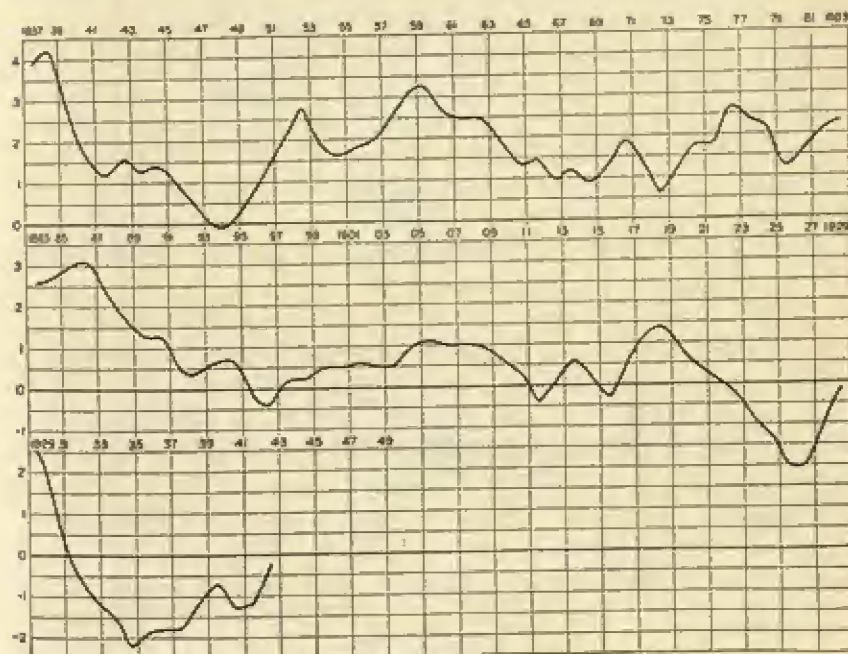


FIGURE 20.—Levels of Lake Huron (minus 581 ft.). Note the cycles of 23, 46, and 91 years. (Yearly means.) Great droughts in the Northwest following 1838, 1880, and 1929 recessions. The grand cycle is 92 years (or better, 91.2). Minor droughts following 1859, 1906, and to be expected following 1952.

United States. They have been very successful in some cases, not so much so in others. Figure 21 shows one of the most successful, again dealing with the precipitation at Peoria, Ill. We employed the precipitation records prior to 1930 to determine the outlines of the periodic terms, and then synthesized the expected precipitation through 1944. As will be seen, 10 years out of the 13 show both in phase and amplitude considerable similarity to the event. The later years betray an increasing tendency for the prophecy to anticipate in phase. This may indicate that some adjustment of length of periods is desirable.

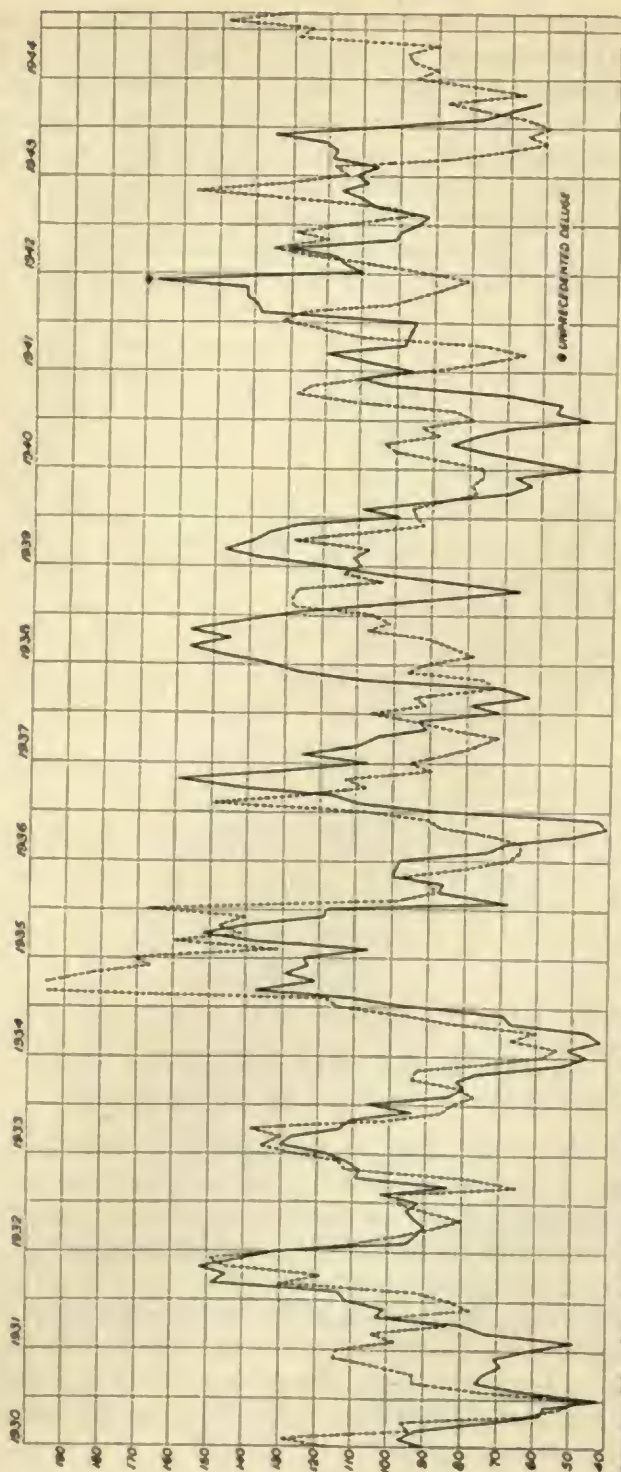


FIGURE 21.—Precipitation percentages at Peoria, Ill., predicted (dotted curve) and observed (full curve). Synthesis of 15 periodicities determined from records for 1853 to 1929.

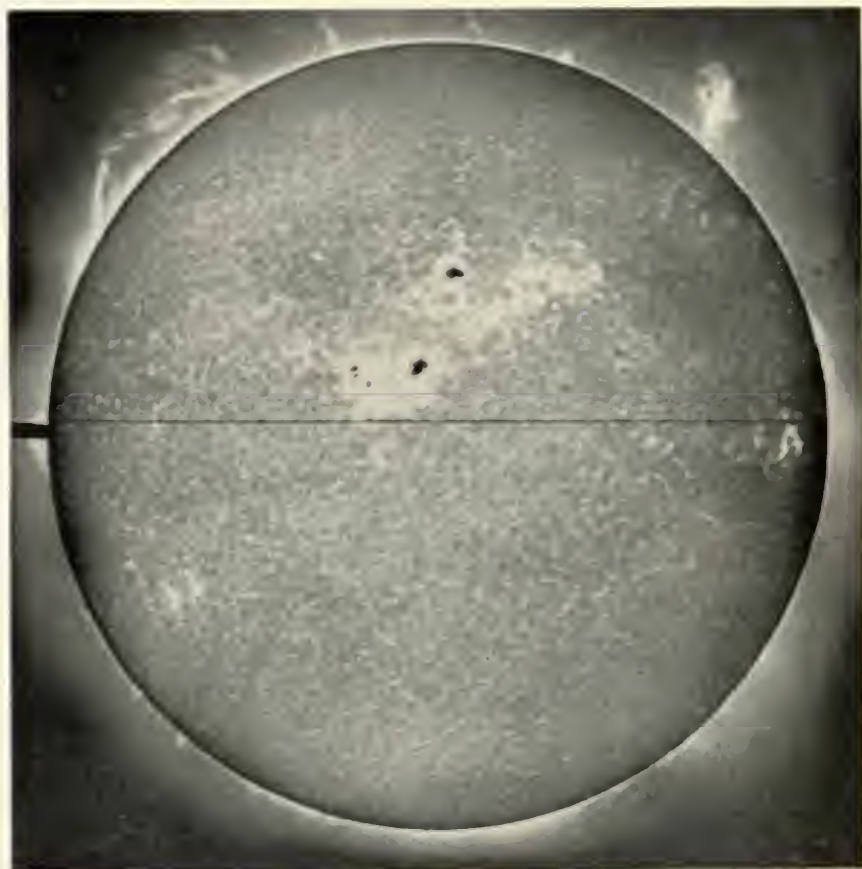
However, if one were content with 5- or 7-year predictions, such shifts of phase could be corrected from time to time.

CONCLUSION

I have brought together many evidences which seem to indicate that the small percentage changes observed in the solar emission of radiation are effective factors in the domain of weather. Many others have been published by H. H. Clayton. The solar measurements involved are exceedingly difficult and require installations on high mountains in desert regions, where the largest percentages of clear skies with low wind velocities prevail. Three stations maintained by the Smithsonian Institution are now engaged in day-to-day measurements of the solar constant of radiation. On account of the variable obstruction occasioned by the atmosphere, laden as it is with clouds, dust, ozone, and water vapor, these three stations are insufficient adequately to follow and record the sun's variation. About three times as many mountain stations, widely separated in the most cloudless and calm regions of the earth are needed. They could be installed for \$500,000, and operated for \$250,000 per annum.⁶

I think there is a great probability that if such additional solar stations were in operation they would furnish information of major value to meteorology. I believe that with the solar data that would then be available, and using the rich store of information regarding terrestrial factors now familiar to meteorologists, great progress would ensue. The neglect of solar variation, which seems to be a major factor in weather, cannot continue if meteorology is to progress as it should. It would be like the play "Hamlet" with Hamlet's part omitted.

⁶ Very recent developments of the research, however, give hope that another approach to the problem not requiring additional stations may be successful.



SOLAR PHOTOGRAPH BY MOUNT WILSON OBSERVATORY, SHOWING SUNSPOTS, FACULAE, AND PROMINENCES.



THE COELOSTAT AND THE PYRHELIOMETER JUST OUTSIDE THE TUNNEL AT MONTEZUMA, CHILE.

ASTRONOMY IN A WORLD AT WAR¹

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I

Science has advanced during the last 4 years both because and in spite of war. Some of the sciences have made tremendous strides as a direct result of the challenge of war necessities. Physics, chemistry, metallurgy, and all the branches of medical science are in this category; some day the full story of their great achievements may be made known. Other branches of knowledge, while far from being unaffected by the war, have continued to advance largely in spite of the upheavals in the life of nations and individuals which world war inevitably brings. Astronomy is in this latter class.

Astronomy and astronomers are playing an important part in the war chiefly along the two lines which have always presented fundamentally stellar problems—direction and time. But the main advances in astronomy in these last 4 years have been made in spite of the war. It is right and fitting and indeed very encouraging that this is the case. When so much that is of intrinsic beauty and of fundamental value is being destroyed by war, and when so many worthwhile activities have to cease, it is good indeed to know that there are astronomers on this continent, and even in some parts of Europe, and in Australia, Africa, India, and probably in Japan, who are able to carry on the continuity of observations on stars and starlight, sun and moon, planets and asteroids, comets and meteors.

If the continuity of observation in many branches of astronomical work were to be completely broken, it would be an irreparable loss to science. Thus it is with satisfaction and great admiration that we read in the Reports of the Royal Observatory, Greenwich, that damage done by enemy action to one of the buildings and to the Airy transit circle has been largely made good, and observations recommenced with that instrument upon Sun, Venus, and the stars

¹ Address of the president of the Royal Astronomical Society of Canada, January 1944. Reprinted by permission from *The Journal of the Royal Astronomical Society of Canada*, vol. 35, No. 3, March 1944.

in the clock and azimuth lists; that parallax determinations are going on; that solar photography and observations of chromospheric eruptions in $H\alpha$ are continuing; and that the two Time Service Stations have operated continuously. During this period the exhaustive work on the solar parallax was brought to completion.

In France solar, planetary, and stellar research have been carried on, and in Holland galactic problems, long-period variables, dark nebulae, and theoretical astrophysics have been under investigation even in these tragic years. In the U. S. S. R., where at least three observatories have been destroyed and another dismantled, plans are already made for resumption of activity and for the erection of new observatories to further the study of latitude variations and solar research. From two observatories east of the farthest battle front we know that papers have been published recently on photoelectric calorimetry and on color temperatures.

Similar records of observations and measurements carried on despite air raids, despite reduction of staff, despite pressing war problems and difficulties of all kinds, could be quoted from many observatories in countries deeply involved in fighting for their very existence.

In these and in countries like our own—at war, but far removed from the main theaters of conflict—there has been a very important contribution made by astronomers in the adaptation of astronomical observations and calculations to the problems of air navigation. The Director of the Glasgow University Observatory, W. M. Smart, has produced three books on nautical astronomy since this war began, and under his instruction, R. A. F. pilots and cadets are learning the art and science of navigation. Scores of astronomers, including Canadian men well known to many of us, are doing similar work, giving all their time, skill, and energy, and often risking their lives in the air with student pilots, in order to impart this so necessary instruction in air navigation.

In the Koran, it is written: "God has given you the stars to be guides in the dark, both by land and sea." Homer tells of Ulysses on his raft that he sat at the helm and "marked the skies, nor closed in sleep his ever watchful eyes." But navigation from the back of a camel or from the bridge of a ship can be a relatively leisurely performance. Not so in a modern airplane! The navigator takes a sight on a star or planet, he reads his chronometer, and then if his calculations take him 5 minutes to perform, he and his plane are already perhaps 25 miles away from the ascertained position. Every minute that astronomers have been able to cut off the time for computation of position is of the greatest value to airmen flying over seven seas and six continents, across enemy lines, with objectives a mere dot on the map—a railway yard, a factory, an airfield.

II

Turning to the subject of time measurement, it is worthy of note that during these war years an accuracy never before dreamed of has been attained. It was in April 1938 that Essen described before the Royal Astronomical Society the researches at the National Physical Laboratory which had resulted in the new quartz clock, of which so much was hoped. This clock makes use of the properties of the crystal oscillator, one of the most reliable and perfect mechanical systems known to man. Essen describes quartz clocks briefly as "consisting of phonic motors controlled via frequency dividers by vibrating quartz crystals." In a paper presented to the Royal Astronomical Society last June, Greaves and Symms record the intercomparisons of three Greenwich free pendulum Shortt clocks, two National Physical Laboratory quartz clocks, and three quartz clocks at the Post Office Radio Branch Laboratories.

They analyze clock errors into three classes: (a) erratic variations in phase, (b) erratic variations in rate, (c) a combination of phase and rate variations, producing a cumulative effect. They show that two Shortt clocks and two quartz clocks may indicate approximately the same mean absolute second differences of relative clock error, but the distribution of errors between the three classes is different—the quartz clocks show very little error of (b) and (c) relative to Shortt clocks, and errors of class (a) do not affect the long-period performance of a clock.

The famous Shortt clocks are now known to be incapable of giving the precision demanded, but the Astronomer Royal hastened to pay them a deserved tribute:

Twenty years ago we had several papers dealing with the performance of the Shortt clocks, then looked upon with great expectations. In this clock was achieved in a simple and beautiful manner what horologists had been striving after for years, namely, a pendulum designed solely for the purpose of beating time whilst being called upon to perform no mechanical work. But if the subsequent performance of this type of clock did not fully come up to our high expectations, the Shortt Free Pendulum has one thing to its everlasting credit—it forced the astronomers to adopt the use of Mean Sidereal Time where formerly True Sidereal Time had been adequate. During the intervening 20 years since this type of clock was installed in many observatories, new requirements have sprung up. In the past the main purpose of a time service was to provide absolute time with an accuracy sufficient for navigational and surveying requirements. But the new use of frequency standards has raised a demand for 24-hour intervals correct to the very high accuracy of a millisecond.

It will be seen then that as absolute standards at Greenwich, Shortt clocks have become obsolete. Our long-range predictions are now based entirely on quartz clocks, free pendulum clocks being used only for extrapolation over an interval of 24 hours.

III

Let us turn our thoughts to cosmology and recall that it was during the first World War that Einstein's general theory of relativity appeared. Two years later, in the war year 1917, came the first suggestion of an expanding universe. This was one interpretation of de Sitter's modification of Einstein's cosmology, implying as it did red shifts of the spectrum lines of faint distant objects. Incidentally, we may turn aside to remark that while de Sitter was then working in a Holland that had been allowed to remain neutral, his spirit is living on in the occupied and battered Holland of this war, and he, though dead, yet speaketh, inspiring his successors at Leiden and Amsterdam to carry on the tradition of astrophysical research in spite of all external difficulties—thus Verweij has produced a theoretical discussion of Stark effect in stellar spectra which was published in Holland and found its way to the United States of America just before the entry of that country into this war. Perhaps I may add that Verweij in that paper dealt a hard blow at a paper by a McGill colleague and myself, though I do not accept it as a knock-out blow. Further research on this controversial subject is now in progress at the Dominion Astrophysical Observatory.²

De Sitter had also deduced from Einstein's theory the four conclusions which offered a hope of observational confirmation. One of these four crucial tests was whether radiant energy passing close to a body with an intense gravitational field surrounding it, would be deflected in accordance with Newton's law of gravitation or with Einstein's modification of that law. It was Prof. A. S. Eddington who realized the great importance of making this test at the first favorable opportunity, namely, at the time of the total solar eclipse which was to occur on May 29, 1919, with the Hyades as background. War or no war, all the plans and preparations were pushed ahead and thus it was that when the eventful day arrived, even though the Treaty of Versailles had not yet been signed, two British expeditions were in readiness to take the crucial photographs. I often reread the passage written by a learned mathematician and philosopher in which he described the meeting of the Royal Society when the results of these eclipse expeditions were announced, verifying as they did the theory of Einstein:

The whole atmosphere of tense interest was exactly that of the Greek drama; we were the chorus commenting on the decree of destiny as disclosed in the development of a supreme incident. There was dramatic quality in the very staging:—the traditional ceremonial, and in the background the picture of Newton to remind us that the greatest of scientific generalisations was now, after

² Recent work at the D. A. O. points to a confirmation of the work of Foster and Douglas on the interpretation of helium profiles.

more than two centuries, to receive its first modification. Nor was the personal interest wanting: a great adventure in thought had at length come safe to shore. [A. N. Whitehead.]

De Sitter's expanding universe suggested an outward motion of the stellar bodies within the framework of space as defined by his modification of the Einstein equation of spacetime geometry. Ten years later, Lemaitre, who had fought with the Belgian army in the war years and afterward entered Louvain University, brought forward his theory of expanding space. This made the radius of curvature of space a function of time, and gave a new stimulus to the astronomers in those great observatories equipped to probe most deeply into space. In the following years, at Mount Wilson and Harvard particularly, the exploration of space was carried on with vigor, and methods were found of estimating the distances of the remote galaxies. A special lens was designed to obtain their spectra at Mount Wilson, and thanks to the broad, strong H and K lines of ionized calcium, red shifts could be measured to distances estimated as 250,000,000 light-years. The correlation between distance and red shift has provided a remarkable confirmation of the theory of the expanding universe. Recessional velocities up to one-seventh the velocity of light have now been observed. In the years between the wars a few voices were heard to question the interpretation of the red shift as a Doppler displacement, but since no alternative explanation suggested itself without postulating some entirely new law of Nature, the expanding universe remained as a working hypothesis in the background of most astronomers' minds.

One of the interesting things that these recent war years have brought is the reopening of this question by E. P. Hubble. Is the universe expanding? Is the red shift actually indicative of motion? Or is the framework of the universe static? And if static, what is the explanation of the displacement of all spectrum lines to the red for distant galaxies? Hubble's analysis of all available data based on the assumption that the universe is expanding, necessitates the calculation of a dimming factor due to recession. When correction is made for this in the estimation of distances, he claims that a map results which is not of homogeneous density, which implies an increasing rate of expansion with distance, and therefore an "age" of the universe totally inadequate. On the other hand when he assumes a static framework for the universe, the analysis of all the data gives a map that shows a linear relation between red shift and distance, and a homogeneity of density. This map has more to commend it than has the former map, and hence the assumption of a static framework appears to be favored. But, as various astronomers have pointed out, the weakness of this result lies in the large probable errors of the quantities involved, so that

even an apparent divergence of 30 percent from uniformity of density is not evidence weighty or certain enough to overthrow the Lemaitre theory of an expanding universe.

IV

Important advances have been made recently by Gamow and Bethe in our understanding of the sources of energy within stars which permit them to radiate energy as they do. Bethe has given an exposition of a cyclical sequence of atomic changes and interactions whose net result leaves a star with fewer hydrogen atoms, but with more helium and the liberation of excess nuclear energy in the form of gamma rays. This is now generally referred to as the carbon cycle and it is too beautiful not to be recorded here, for though published a few months before the war, it has been during the war years that it has become a part of astronomical thinking. Of the six stages, four result from collisions with hydrogen atoms in the deep, hot interiors of main sequence stars, and two are spontaneous disintegrations of unstable nuclei.

1. $C^{12} + H^1 = N^{13} + \gamma$
2. $N^{13} \rightarrow C^{13} + \text{positron}$
3. $C^{13} + H^1 = N^{14} + \gamma$
4. $N^{14} + H^1 = O^{15} + \gamma$
5. $O^{15} \rightarrow N^{15} + \text{positron}$
6. $N^{15} + H^1 = C^{12} + He^4$

The two positrons rapidly interact with electrons to give rise to gamma radiation. Thus is produced the penetrating radiation, most of which in the course of its progress toward the boundary of the star becomes transformed into the heat, light, and ultraviolet radiation that pour out from the photosphere. The central temperatures of the cool giant stars are insufficient to maintain this active cycle, but theory can explain their radiant energy in terms of atomic collisions and transmutations which are, however, noncyclical. Hydrogen, deuterium, lithium, beryllium, boron are slowly transformed into helium.

If the central regions of the hottest stars are not the crucibles of nature wherein the elements are built up, where and under what conditions were they formed? A highly speculative answer is to be found in an intensely interesting piece of theoretical research carried out during the early years of this war by Chandrasekhar and Heinrich. They have been inquiring under what conditions of nature the basic units of matter—electrons, protons, neutrons, positrons—could be expected to come together to form, in their various proportions, the atoms of all the isotopes of the elements familiar to the chemist. As

these elements compose all stellar bodies as well as all things terrestrial, their synthesis is a cosmic problem. They find that such tremendous extremes of high temperature and high density would be required that it is necessary to suppose that all the matter of the known universe was once confined to a volume of radius only about twenty times that of the solar system. Such a sphere drawn around our sun as center does not now contain a single other star. Yet into such a volume there may once have been packed not only all the thousand million stars of our own galaxy, but all the millions of other galaxies. This is indeed a picture reminiscent of the "giant molecule" of Lemaître. Since stars and galaxies are not now thus packed, expansion must have taken place some time very long ago. The present rate of expansion is such that galactic distances are doubled every 1,800 million years. This gives the time elapsed, since the expansion began, as several thousand million years which is in satisfactory accord with the age of the earth as determined by other physical lines of approach and regarded necessarily as a lower limit for the age of the universe.

The last chapter on these cosmological problems is not yet written—indeed there may well be many chapters yet to come and still no last chapter in sight. It is the glory of the quest that as men seek the unexplored horizon the margin fades forever and forever as they move.

V

An investigation of very recent date has led to positive conclusions about planetlike bodies associated with stars other than our sun. There is strong evidence for this in the case of 61 Cygni and 70 Ophiuchi. This may be the beginning of a new search and a new certainty in a field of astronomy hitherto theoretical and speculative. Already several astronomers on two continents are studying the implications.

Another astrophysical problem that has been worked upon with considerable success during these war years, is the old backlog problem since 1869 of the solar corona. At Uppsala, Edlén has been examining the X-ray and ultraviolet spectra of some very highly ionized atoms, and a year ago his 1942 paper was received in England and also in the United States of America. He uses his laboratory data as basis for calculation of forbidden lines and altogether he identifies 17 coronal lines with lines of Fe X, XI, XIII, XIV, XV, Ni XII, XIII, XV, XVI, Ca XII, XIII, A X; and two other lines less certainly with Ca XV and A XIV. The ionization potentials required to produce such atoms are very high, actually 233 volts for Fe X, 655 volts for Ca XIII, and at first this seemed to offer an insuperable obstacle to

acceptance of Edlén's proposals. The age-old question of Nicodemus arose—how can these things be? These atoms are many thousand miles from the photosphere of the sun; and to produce such ionization, temperatures of 2,000,000 degrees are necessary. Speculation and calculation have followed. A few months ago an explanation was given in a letter to *Nature* by V. Vand of London. Even higher temperatures he shows to be possible in the low-density regions of the corona as a result of collisions of high-velocity atoms falling toward the sun from interplanetary space. With the greater density of the inner corona and consequent increase in radiation losses, he believes conditions may be favorable to just those transitions postulated by Edlén.

VI

The numbers 136, 137, 256 will awaken in the minds of many of you memories of a kindled interest, of perplexity, doubt, expectation, and perhaps of moments of great thrill, as you think back over the last 15 years. One name alone stands central among these memories—that of Sir A. S. Eddington. This has been his playground pre-eminently. Some of us have stood fascinated at the edge of the field watching this illusive game played patiently, skillfully, brilliantly by one man, a master juggler with the elements of the theory of groups, with quantum mechanics, and with the basic units of measurement, producing, as from the proverbial hat, physical constants both atomic and astronomical. Some there have been who paused to watch briefly, to smile or even ridicule the Aristotelian tour de force. But steadily and doggedly the theory has been pushed forward, several papers having appeared in the last 3 years until now the evidence is overwhelmingly great that, with no observational data other than three basic constants, namely, the velocity of light and the Rydberg and Faraday constants for hydrogen, it is possible to calculate theoretically the following 13 physical constants: charge e ; Planck's constant; masses of electron, proton, hydrogen atom; gravitation constant; fine structure constant; nuclear range-constant; nuclear energy-constant; mass of universe; number of particles in universe; Einstein radius of space; nebular speed. This is a striking achievement.

Let us look briefly at just two of these constants. The recessional velocity of the spiral nebulae is calculated to be 572.36 km. per second per megaparsec. The observational value of Hubble and Humason is 560. When the great 200-inch reflector comes into action, we shall expect to see the observational value come closer to Eddington's determination.

The number of independent quadruple wave functions at any point is $2 \times 136 \times 2^{256}$ or 3.15×10^{79} and in his earlier work Eddington iden-

tified this with the number of particles in the universe. Since 1939 he has found that a question of nonintegrability in spherical space necessitates a reduction of 25 percent; so the number given in his 1942 paper is 2.36×10^{79} .

This theoretical approach has now reached a point where its author can write "I think the theory now deserves to be the accepted theory—my definition of an 'accepted theory' being that it is the theory which is so far right that everyone is interested in trying to discover what is wrong with it." Can we wonder that he pauses in his work to refer to "the devastating beauty of quantum arithmetic." This entire investigation must surely rank as one of the great adventures of the human mind exemplifying Blake's stately metaphor—"Imagination goes forth in its uncurbed glory."

VII

This brief survey of a few fields of astronomical research, incomplete as it obviously is, will serve nevertheless to indicate that pure science is not dormant, much less is it dead, during the terrible years when the vile demoniacal God of War stands astride the earth. For many years the International Astronomical Union has been an influence for understanding, and for cooperation in the search for knowledge with mutual respect and trust. It is temporarily in abeyance, but it will once again rise to carry on its good work. The lesson of astronomy down the centuries has been one of international interdependence and mutual indebtedness.

The problems facing mankind are very complex—the dealings of man with man, the attitude of nation to nation. No solutions making for international good will and world peace will be achieved by men of narrow mind, myopic sight, and dwarfed soul. The far vision in time and space, the winged imagination that leaps the barrier of here and now—these are the qualities of mind and spirit needed in every walk of life and needed superlatively in the leaders of every nation if in the years just ahead of us progress is to be made toward the great ideal of international unity. How can the eyes of the blind be awakened to the dazzling vision of the City of God? For some it may be by the contagious enthusiasm of a great teacher or leader, for others the illumination from poetry, for some the spark is kindled by the study of history, or of philosophy, and for yet others it is through natural philosophy and astronomy. Mankind needs the perspective of the cosmic background. "The great values," said Field Marshal Smuts, "retain their unfading glory and derive new meaning from a cosmic setting."

There is a challenge to the scientists and to the lovers of science to teach the boys and girls, the young men and women of today and

tomorrow, the ideals, the aims, the methods, and the integrity of the scientific approach to facts and to problems.

We do not forget the dictum of Rabelais, "Science without conscience is damnation." Wartime drives this home with bitter and tragic intensity. But we may say with great assurance that science with conscience has an essential part to play in procuring and maintaining world conditions in which peace can endure.

All who have the ideal of world citizenship at heart, all who have the far vision of things that have been and of things that may be, and the realistic grasp of things that are, must cooperate in the great task of bringing into the affairs of mankind upon this earth some semblance of the order, beauty, and harmony of the universe of stars. Toward this end, both directly and indirectly, astronomy and astronomers can play a part; and it may prove to be a part which no one else can play for them because they, the astronomers, are the people with the fullest understanding of the cosmic background.

THE STRUCTURE OF THE UNIVERSE¹

By CLAUDE WILLIAM HEAPS
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It may seem, at first sight, presumptuous to attempt the discussion, in one hour or less, of such a comprehensive topic as the structure of the universe. Actually the subject is not as big as it sounds. There are, in one sense, as many universes as there are individuals; but the universe in this personal sense will be ruled out of the present discussion. A tremendous simplification is at once achieved when we limit our topic to the physical universe. We now inquire, what is the physical universe?

Eddington has defined it as the "theme of a specified body of knowledge, just as Mr. Pickwick might be defined as the hero of a specified novel." Such a definition emphasizes the epistemological point of view and therefore it suffers from lack of definiteness and simplicity. There is beautiful directness and decisiveness in the attitude of the mathematician who wrote an equation on one line in one of his published papers and said, "This equation contains everything we know about the physical universe." The conciseness of the language of mathematics is probably nowhere better exemplified than in this equation. On the other hand, the universe, if it can be described in terms of mathematical symbols and with one equation, may not seem like such a big subject after all.

To the physicist, matter, space, and time exist outside the human mind. The physical universe is an objective, dynamic arrangement of all matter, space, and time. In discussing the structure of the universe we merely attempt to describe some of the features of this arrangement.

Before beginning such a description it seems necessary to indicate just how it is related to human welfare—since the general title of this series of lectures is "Science and Human Welfare." I am venturing to interpret the phrase "human welfare" in the broadest possible sense. There are many types of scientific investigation which do not appear to have any direct bearing on the pleasures or pains of the

¹ Public lecture delivered at The Rice Institute in the spring of 1943. Reprinted by permission from The Rice Institute Pamphlet, vol. 30, No. 4, October 1943.

human race. The discovery of the planet Pluto cannot be said to have done very much toward raising the sum total of human welfare, in the ordinary sense. But in the broadest sense, it may be said that the welfare of a nation is closely tied up with the capacity of that nation for untiring search after truth. Intellectual unrest, intellectual curiosity is, we like to think, essential to the true growth and development of a people. A dairy company advertises that its milk comes from contented cows. A rival company is perhaps more progressive in its views when it advertises that its cows are not contented—they are always trying to do better.

The thesis is, then, that the pursuit of pure knowledge is indicative of a healthy national mind; that full development of intellectual activity, whether it be in the matter of investigating the stars or in building a better radio, is essential to the true welfare of a nation. The Russians asked a captured Nazi why he came into their country. He replied, "I am just a little man, I do what the Führer says." A nation is facing tragedy when free speculation is discouraged, when science is devoted solely to control of men and machines and to the production of a workable mass of "little men."

To begin this discussion of matter, space, and time we will try first to systematize our ideas of space, or size, in relation to matter. Imagine a long, horizontal line drawn so as to represent the "the x-axis." Let all objects in the universe be placed along this line in the order of their sizes. The smallest objects will be placed near the beginning of



FIGURE 1

the line, at its left end. Larger and larger objects will be placed farther and farther to the right. We next divide the line into two parts by a vertical line. All objects to the left of this vertical line are too small to be seen with the naked eye, so this region is called the *microscopic* region. In it are placed different kinds of particles such as molecules, atoms, the proton, the neutron, the mesotron, the electron, positron, and neutrino. These particles are placed nearer and nearer to the origin of the line as they become smaller and smaller. It is worth noting that nature seems not to have given us anything smaller than the electron, in spite of the fact that there is plenty of room for particles between the electron and the origin of the line.

To the right of the vertical dividing line we place all objects large enough to be seen with the naked eye. This region is called the *macroscopic* region. We might put in here, stones, mountain, earth,

solar system, spiral nebulae. The farther end of the macroscopic region may be given a special subtitle, the *astronomical* region.

We have arranged here various matter elements in a certain spatial relationship. The time concept is involved because this is an arrangement which may be correct only at one instant of time. It is possible that the position of some of these entities on the line is constantly changing. When an electron gets into rapid motion its mass is changed a little and it shortens one of its dimensions. It thus shifts its position on the line slightly to the left whenever it has a high velocity. The solar system may be slowly running down so that the planets gradually approach the sun. If this is the case the position of the solar system on the line is slowly shifting to the left.

Certain segments of this line have occupied the attention of various specialists. Astronomers deal with everything listed to the right of earth. Thousands of specialists work on the section from earth to atom. Physicists in recent years have concentrated intensively on the segment from atom to zero. The discovery of the positron, the neutron, and the mesotron within the last decade, has opened up a most fruitful field of research in physics. In this region, forever beyond the reach of the human eye, is probably contained most of the mystery of the entire universe. As K. K. Darrow has expressed it, "This field is unique in modern physics for the minuteness of the phenomena, the delicacy of the observations, the adventurous excursions of the observers, the subtlety of the analysis, and the grandeur of the inferences."

It is not too much to say that if some American physicist could only make the right kind of discovery in this domain our entire oil and coal industries would become more or less obsolete and World War II would be won in a matter of days. It should also be said that such a discovery is possible but not probable.

Returning now to our linear lay-out for the universe we may note that everything to the right of proton is constructed out of the material included in the range from proton to zero. All matter in the universe exists in the form of bunches or aggregates of smaller parts. Protons, neutrons, electrons bunch to form atoms; atoms group into molecules; molecules group into stones and mountains; stones and mountains form the earth. In the astronomical field, planets group about the sun to form the solar system—a solar system which in the astronomical field is remarkably like the atom in the microscopic field.

The important unit of structure in the astronomical field is a sun. Practically all the stars which we can see on a clear night are distant suns, much like our own, although it is thought that only an extremely small fraction of these suns have planets around them like our own.

All these suns which can be recognized distinctly are grouped in a sort of flattened, disklike bunch which is whirling in empty space. Our own sun and planetary system is a member of this group, being located about 30,000 light-years² distant from the center, or hub, of this gigantic disk. When we look into space along the plane of the disk the stars seem to be distributed very densely. We see the milky way. This bunch of suns is called a spiral nebula. It is sometimes called a galaxy, or an island universe. The word "universe" in this sense has a restricted meaning because our island universe is not the only one in existence. There are millions of others distributed throughout space as far as our most powerful telescopes have been able to penetrate.

The nebulae are by no means recent discoveries. Sir William Herschel, 150 years ago, suspected that they were distant groups of stars. The philosopher Kant believed that they were "systems of many stars, whose distance presents them in such a narrow space that the light which is individually imperceptible from each of them, reaches us, on account of their immense multitude, in a uniform pale glimmer." They have been described as looking like "candlelight seen through horn." A rough diagram, not drawn to scale, is given in figure 2 to indicate the total extent of the entire universe which has been observed, up to the present, with our most powerful telescopes.

We might now indicate on the linear lay-out of figure 1 the approximate size of the largest bunch of matter, the spiral nebula, as 100,000 light-years. Also we might speculate as to the possibility of nebulae themselves forming still larger groups. Extensive surveys have been made by the astronomers at Harvard and Mount Wilson, of the distribution in space of the nebulae, and there is, indeed, evidence of grouping of nebulae. It is legitimate to add another bunch of matter to the line lay-out—the supernebula, or supergalaxy.

The supergalaxy is the largest known aggregation of matter in the universe. Its diameter may be of the order of a million light-years. At least that is the estimate made by Harlow Shapley of the diameter of the group of nebulae in which our own is located. Our local group contains perhaps 15 or 20 nebulae, but in some supergalaxies there are hundreds of members.

So far, then, our picture of the universe reveals a granular, or atomic structure. We start near the zero point of size, with a particle of definite size. A fundamental law of attraction operates to cause the small particles to group together to form larger particles, these larger particles again group to form still larger particles, and so on until we reach the limit of observation, the enormous supergalaxy.

² A light-year is the distance which light travels in one year. It is approximately 6,000,000,000,000 miles.

We are unable to put a stop at the right-hand end of our line, as we have done at the left end. Space may go on into infinity—possibly matter may go on bunching up into larger and larger aggregates with no limit as to the ultimate size of any final bunch, because there may never be any final bunch. Speculations of this kind may be interesting but they are not of much significance otherwise, because they take us outside the realm of possible human experience.

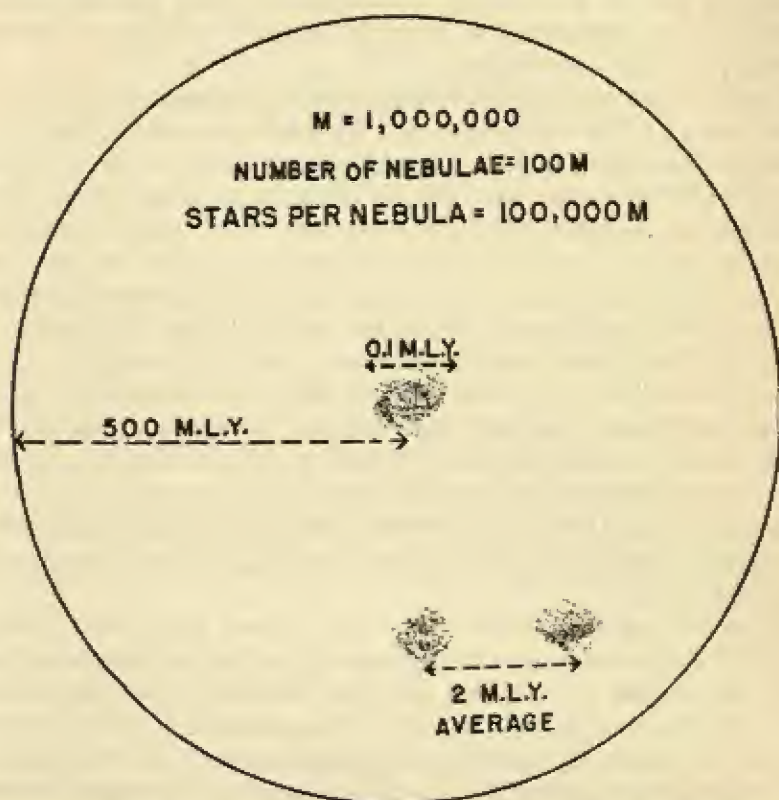


FIGURE 2.—Sphere of view of the 100-inch telescope. Distances are in light-years, L. Y., and the diagram is not to scale. Our earth is about 30,000 L. Y. away from the center of the central nebula above.

It seems probable that in detecting the supergalaxy man has reached the limits of observation in his probing of the depths of space. The new 200-inch telescope will be doing a fine job in helping to chart and analyze these enormous groups of matter.

The line diagram of the universe, limited at one end by the electron, at the other by the supergalaxy, has given a rather simple picture in terms of two variables, space and matter. The third variable, time, must now be considered. We have to consider the relationship between the various units of our structure as this relationship may

change from time to time. Newton's Law of Universal Gravitation says that every particle of matter in the universe attracts every other particle. If forces of attraction cause matter to bunch up into aggregates of various sizes, why may not the various bunches themselves start coming together until eventually there results just one large, static bunch of matter floating quietly in an infinity of space? Such an end result seems logical, but it cannot happen until the kinetic energy of matter, the energy of motion, has been converted into radiation and transferred to infinity. Such a transfer of energy appears, in fact, to be going on.

A study of the motions of the various aggregates may be expected to throw some light on this question. We start with the smallest particles, electrons, for example. In addition to random motions caused by collisions with other particles, all electrons are supposed to spin. They may be thought of as being like tops which never run down. When an electron helps to form an atom, in addition to spinning it also revolves about the nucleus, just as the earth revolves about the sun. The aggregations of matter between atom and earth on the diagram of figure 1 may have various kinds of motion but when earth is reached we again have the spin about an axis and the revolution about the sun. Our sun, together with all the other suns in its group, forms a nebula which spins with high speed about a central axis. The spin velocity is very high, but the size of our nebula is so great that it takes about 2 million centuries for it to make one revolution. As Shapley puts it, this is the time required to "click off one cosmic year."

The motion of the supernebula is not known in accurate detail. It is possible that some sort of gigantic spin is present here also, but so far such a spin has not been detected. Instead, a very surprising sort of motion has been discovered, a motion which is just contrary to what we expect if matter is to agglomerate into one big bunch. The supernebulae appear to be receding from us. The supernebula to which our galaxy belongs maintains its fixed dimensions, and behaves more or less as a unit, but all the other supernebulae appear to be flying away from ours with high speeds. The farther away from us they are, the faster they seem to recede. There seems to be no good way of explaining such a phenomenon. One might assume that a primeval explosion started all matter out in all directions from an original concentration, but there are serious difficulties involved in such a theory.

The whole question of the expanding universe is definitely controversial. The consequences of accepting or rejecting the theory are so great that it will be worth while to review briefly the evidence.

Suppose the lights of a very distant city are observed at night through a telescope. The various spots of light all look much alike. However, they are not all the same in character. Some may be caused by incandescent lamps, some by neon signs, some, perhaps, may be due to the newer type of yellow sodium lamp used for illuminating highways.

We now put a glass prism in front of the telescope objective. The telescope must be deviated sideways, if we are to see the city through the prism and the telescope. When we do see it, each spot of light appears to be smeared out into a band of color. The colors present in each spot of light are separated and spread out and we can see just what colors are present in the light from each source. The neon signs are characterized by definite colors in the orange and red; the sodium lamps can be recognized by the fact that only one color, yellow, is visible.

If we were to photograph the lights of an enormous city from an enormous distance the whole city would appear as a small, luminous spot. The prism would smear out the separate lights of which the spot is composed, but they would all be superposed in a single smeared spot for the whole city. However, if there were a large number of sodium lamps one point in the smear would be brighter than the rest because there would be an excess of the yellow sodium light.

A nebula, consisting of millions of suns a long distance away, behaves like our hypothetical city except for one small difference. Light from a sun has *dark* absorption lines or bands from which color is missing as a result of absorption in the sun's atmosphere. There is a dark line in the spectrum of our own sun, corresponding to absorption of hydrogen in the sun's atmosphere. This dark line always appears at the same place in the spectrum no matter what kind of a source, and always means that hydrogen is present. Dark lines appear in the nearer nebulae about where they should be in the spectrum. For the more distant nebulae, however, they are shifted toward the red end of the spectrum.

There is only one known explanation for such a shift of a spectral line. If the source is moving away from an observer the light received appears redder than when the source is stationary. This phenomenon is called the Doppler effect. It is a matter of common experience in the field of sound. The pitch of an automobile horn is lowered as the horn passes rapidly by an observer and recedes from him.

The photographs of the nebulae show that the hydrogen absorption line is shifted farther and farther away from the normal position as

the pictures go to more and more distant nebulae. The amount of the shift gives the velocity of recession. Many nebulae have been observed and the conclusion is reached that for every million light-years' distance from the earth the velocity of recession is increased by about 100 miles per second. The farthest nebulae observed are flying away from us with a speed of about 25,000 miles per second.

It is well to weigh critically the evidence for results like these. As regards estimates of nebular distances, the methods used by astronomers seem entirely adequate. In the nearest nebula individual stars can be seen. Some of these stars fluctuate in brightness with a period of $5\frac{1}{3}$ days. Similar stars, known as Cepheid variables, are found in our own nebula, and the distances of a few of them have been determined by ordinary engineering methods. It is found that these stars are all of about the same size, so that if one Cepheid variable is much fainter than another its faintness may be attributed solely to its greater distance. The distance of the nearest nebula can thus be determined with considerable accuracy by comparing the brightness of one of its Cepheid variables with the brightness of a similar star in our own galaxy—a star whose distance has been measured by reliable methods. Having a good estimate of the distance of one nebula it is legitimate to infer that other nebula of the same type are fainter and smaller only because they are farther away. It is thus possible to estimate their distances. The results of these estimates might give occasional large errors, but when a great number of observations are made the individual errors must average out fairly well.

As regards the shift of the absorption line toward the red, a good many attempts have been made to explain it in some other way than by the Doppler effect. So far, all these attempts have failed or encountered logical difficulties. During the last few years, however, certain evidence has accumulated which has brought about a paradoxical situation in the theory of the expanding universe. There are some very serious objections to the theory. First, let us suppose that our explosion hypothesis is more or less in accord with the facts. After all, if the nebulae are now observed to be scattering they must at some previous time have been more closely bunched. It is not difficult to calculate how long ago it was when the nebulae were all together and touching each other. We know how far away they are now, we know how fast they are receding, and how their velocity of recession varies with the distance from us. These data enable us to calculate the time when they must have started. According to Hubble, after all corrections have been made this starting time was about 1,000 million years ago. Unfortunately this is only a fraction of the age of the earth—indeed there is evidence that life actually existed on earth that long ago. It is difficult to see how our earth could exist in its present form

at a time when all matter in the universe was assembled and ready for a cosmic blow-out of such tremendous proportions.

So much for objection number one. The second objection arises as follows. When a source of light moves away from an observer there are two effects produced. The first, the Doppler effect, has been mentioned as a change of color, a reddening of the light. A second effect is a decrease of brightness, known as the "dimming factor." It is easy to see why a light should appear to be dimmer when the source moves away from the observer. Suppose a stationary machine gun is firing bullets at a fixed target at the rate of five per second. Then every second five bullets hit the target. However, if the gun is moving away from the target, still firing five shots a second, there will not be five bullets hitting every second. The bullet discharged from the gun at the end of a given second will have had to traverse a greater distance than the bullet which was fired at the beginning of the second, so it will take a longer time to reach the target. Perhaps only four bullets will hit the target in one second. The extra bullet has gone to fill the extra space in the bullet stream—the extra space created by the recession of the gun. The case of a light source is exactly analogous.

Now in estimating the distance of a nebula its brightness is taken as a criterion of the distance. The question arises as to whether the dimming factor should be applied when making the distance estimates. If the nebulae are actually moving away from us then the factor must certainly be applied. If the reddening of the light is not caused by a velocity of recession then the dimming factor must not be applied. With such tremendous speeds of recession this factor makes quite a big difference in results.

The following discussion is very largely quoted from the annual Sigma Xi lecture delivered in December 1941 at Dallas by E. P. Hubble of the Mount Wilson Observatory. Dr. Hubble is one of the world's foremost authorities on the subject of nebulae.

Let us first suppose that the reddening of the light is *not* caused by a velocity of recession. It may be due to some hitherto undiscovered and unknown phenomenon. We can then estimate distances without any dimming factor and a survey can be made to find out how the nebulae are distributed throughout the region of space within our present range of view. Such surveys have been made at Mount Wilson and Mount Hamilton, out to a distance of 420 million light-years. Data have also been obtained and analyzed at Harvard, and the net result indicates a fairly uniform distribution of nebulae throughout the observable regions of space. There are, on the average, just as many per unit volume at great distances as in the immediate neighborhood of our own group.

This result is intellectually very satisfactory. In fact, it agrees with a fundamental principle of cosmological theory, a principle which has been postulated by theorists for no other reason than its appeal to our sense of order and the fitness of things. This principle states that the universe, on a grand scale, will appear much the same from whatever position in space it may be viewed or explored. This principle of cosmology is satisfied, therefore, if the nebulae are not assumed to be receding.

We next investigate the consequences of assuming the red shift to be due to a real velocity of recession of the nebulae. The dimming factor must now be applied in estimating distances, with the result that the most distant cluster is actually about 13 percent fainter than it would be if it were stationary. The scale of distances is thus altered, so that when we make our space survey to find out how the nebulae are distributed it turns out that they are no longer scattered uniformly. The number per unit volume increases steadily with their distance away from us. Here is a result which is intellectually very disquieting. The cosmological principle of no favored position is violated. We might be willing to accept this violation if it went the other way, that is, if the density of nebulae decreased with distance. Then we would conclude, very happily, that we had discovered another super-supergalaxy, another big matter bunch to put out on the right-hand end of our linear lay-out. No such interpretation can be given when the nebulae are found not to thin out at big distances, but actually to become more dense in numbers.

It may seem obvious to the layman that we ought to discard the idea of an expanding universe. It makes us worry about the short time which has elapsed since the original cosmic explosion occurred; it bothers us with an increasing density of matter as we proceed farther and farther into the depths of space; and the only evidence we have to go on is a series of pictures, rather hazy, smeary pictures, in fact, with a light patch shifted too far to one side.

The physicist and the astronomer, unfortunately, cannot treat these fuzzy pictures in such a cavalier manner. There is no denying the existence of the shifted light patch in the pictures, hazy though it may be. There is no denying the fact that all such similar shifts of color have been explained satisfactorily by the Doppler effect and by the Doppler effect alone. One is reminded of the saying of the old colored man, whose years of experience had developed a certain ripe philosophy of life. "It ain't so much what you don't know that gets you into trouble, it's what you do know and ain't so!"

There are several ways, more or less unsatisfactory, of escaping from the dilemma of the expanding universe. The first way is not

a good way, but like other escapist philosophies it must be considered and estimated for what it is worth. It involves spatial curvature.

The idea of curved space is now quite a familiar idea to most people. Eddington, Jeans, Einstein, and others have written books for popular consumption and the sales have been very gratifying. Even the pulp magazines do not hesitate to invoke the fourth dimension as a mode of escape for the hero or the villain. A simple way of approaching the concept of spatial curvature is as follows. Think of a straight line along one dimension. Given a second dimension at right angles to the first, then we have the possibility of curving the line into the second dimension. Think of a plane surface, like a sheet of paper flat on a desk. Given a third dimension, at right angles to the desk, we have the possibility of curving the paper sheet into this third dimension. Think of a solid filling three dimensions. Give a fourth dimension at right angles to the other three, we then have a possibility of curving the solid into the fourth dimension. It is only because we have three-dimensional minds that we cannot see this fourth dimension.

A mathematician may speak of space itself as being curved without reference to any solid matter in it. For example, consider the earth to be perfectly smooth. If we were two-dimensional creatures instead of being three-dimensional, we might draw a big circle on the earth's surface, measure its diameter and its circumference, and then find that the circumference was not equal to π times the diameter. We would not know that the circle was not flat (since we are assumed to be two-dimensional), but we could certainly infer a curvature of our flat space and even determine its radius if we knew enough about ordinary Euclidean geometry, which would work pretty well for small circles on the earth's surface.

The mathematical description of the universe to which allusion was made at the beginning of the lecture involved curving of three-dimensional space in somewhat the same fashion as described above for the two-dimensional space. If space actually is curved in this way our ordinary solid geometry, Euclidean geometry, would not be quite correct. In order to find out whether it is correct, measurements of certain kinds must be made. For example, if a negative parallax could ever be observed for a single star, a spherically curved space would be implied. The mathematician Schwarzschild, a good many years ago, attempted to find what curvature of space would be possible according to certain types of non-Euclidean geometry. In dealing with these geometries he said, "One there finds oneself, if one but will, in a geometrical fairyland, but the beauty of this fairy tale is that one does not know but that it may come true."

Schwarzschild's results need not be considered here because his data were limited and because we have at present more detailed modes of procedure than he used. There are at least two mathematicians who have achieved the unique distinction of having a universe named after them. They are Einstein, and a Dutchman named de Sitter. Both universes are non-Euclidean and the Einstein universe appears to be the more popular. The curvature of the Einstein universe is determined by the amount of matter in it, and if it is not a static universe, by certain other factors. A chunk of matter produces quite a large local curvature, which is evidenced to us by what we call gravitational attraction.

This universe is not infinite in extent. It is a closed universe with a finite volume but having no boundaries, just as the surface of a sphere is a closed surface of finite area yet has no bounding edges. In this universe one might expect to see a star in two directions, first by looking directly at it, second, by looking in the exactly opposite direction at light rays which have gone completely around the circuit of the universe in the opposite direction. Star images have not been seen in this way, possibly because their light is too faint after the long trip around the universe. There is also the possibility that the theory is wrong. It has, however, been seriously suggested that two very faint nebulae, observed in a certain direction, may actually be the backs of two of our nearest neighbors, as seen the long way around.

The theory of a finite, closed universe is very attractive in many respects. We may again use the term "intellectually satisfactory" in this connection, largely because this universe can be given a concise mathematical description and in terms that explain the gravitational effects of matter. There is also, in many individuals, a definite repugnance to the idea of infinite space. In discussing the stars Kant, in 1755, says, "There is here no end, but an abyss of real immensity in presence of which all the capability of human conception sinks exhausted." The finite mind likes to set up a blank wall somewhere, in order to end it all. It is probably intellectually satisfactory to know that one can start out in imagination and not have to get farther away forever and ever, but will eventually get back to the good, old, familiar region of the starting point.

With this picture of a finite, closed universe in mind we may now return to the question regarding the nebulae. Why should they appear to be crowded together at great distances from us? The answer might be that the curvature of space appears to make them crowd into smaller and smaller volumes as their distance increases. If this is true it is possible to calculate what radius of curvature of the universe would give the observed apparent crowding of the

nebulae at great distances. Such calculations have been made and the universe turns out to be remarkably small. In fact, it is so small that our largest telescopes would allow us to see about one-sixth of the way around it. This small universe is required in order to explain the apparent nonuniform distribution of the nebulae. However, if we calculate the radius of the universe in this way we are obliged to have only a certain amount of matter in it, since, according to Einstein, the radius is determined by this total amount of matter. Hubble has made surveys to find out whether the observed amount of matter will fit in with the radius as determined above. He estimates that if all observable stars and nebulae were smeared out uniformly there would be a maximum of about one hydrogen atom per cubic meter. This density of matter is far too small. In other words, there is not enough matter in the universe to give it a curvature great enough to spread out the nebulae uniformly. The theory of curvature of space has, therefore, failed to resolve the problem.

Another way out of the dilemma is to suppose that the observations of the astronomers are in error. Here is what Hubble has to say.

These questions have been carefully reexamined during the past few years. Various minor revisions have been made, but the end results remain substantially unchanged. By the usual criteria of probable errors the data seem to be sufficiently consistent for their purpose. Nevertheless, the operations are delicate, and the most significant data are found near the limits of the greatest telescopes. Under such conditions it is always possible that results may be affected by hidden systematic errors. Although no suggestion of such errors has been found, the possibility will persist until investigations can be repeated with improved techniques and more powerful telescopes. Ultimately the problem should be settled beyond question by the 200-inch reflector destined for Palomar.

This telescope will have about twice the range of the best one now in use. Work on it has been stopped by the war, so it is impossible to predict just how soon it can be put to work on this problem.

The last way which may be suggested for escaping from the dilemma is to suppose that in the region of astronomical magnitudes some new principle of nature is operative—some principle which we have not yet discovered in the ordinary macroscopic field. Such a principle would have to free us from the necessity of using the Doppler effect, and we would no longer have to say that experimental observation shows the universe to be expanding. This new principle would, therefore, have to explain why the light from nebulae gets redder and redder as it travels greater and greater distances. Perhaps light which has been traveling for 100 million years in a straight line exhibits its senility by a decrease in the frequency of its vibrations. We do not know of any possible reason such as this why old light should be different in any way from new light. The only place

from which we can get really old light is from the distant nebulae, so our chances of establishing by experiment a new principle of physics like this seems at present to be involved in a vicious circle from which there is no escape.

It appears, therefore, that our knowledge of the structure of the universe at the limits of the astronomical range is unsatisfactory. We have to recognize that there are discrepancies between theory and experimental observations. Hubble says that "a choice is presented, as once before in the days of Copernicus, between a strangely small, finite universe, and a sensibly infinite universe plus a new principle of nature."

We may now go back once more for a comprehensive view of what we have called the linear lay-out of the universe in figure 1. The three components, or variables, were assumed quite simply to be space, matter, and time. At the right-hand end of the scale we have become embroiled in some rather questionable speculations regarding the nature of space and the behavior of light. In this region, where a light-year is the unit of distance and a nebula the unit of mass, we have good reason for suspecting that the mechanics of the universe cannot be described or explained in such a simple way as in the region of miles and mountains.

Peculiarly enough, if we go from the enormously great region to the extremely small region, the region of the electron and the positron, we encounter similar difficulties. You will remember that Darwin characterized the microscopic region as unique because "of the adventurous excursions of the observers," and "the grandeur of the inferences." One or two of these inferences and excursions may be cited here, and it will appear that the simple concepts of space and matter have suffered in the microscopic field in much the same way that they have suffered in the astronomical field. As the result of investigations in the field of the small particles it has become necessary to broaden our ideas as to the nature of matter. Cloud-chamber pictures have allowed us practically to see two particles of matter created in space from the energy contained in radiation.

The thing that happens is that a photon, an atom of radiant energy traveling with the speed of light, somehow gets itself into a peculiar situation in a microscopic field of some kind. The result is that the photon changes into two particles with electric charges, a positron and an electron.

In the macroscopic size range an equivalent phenomenon would be for a quantity of sunshine, passing by an iron ball, to change suddenly into a couple of buckshot.

Needless to say, no one has ever seen anything like this happen. It is only when sizes become so small as to prevent direct observation

that the event occurs. We may well say that something peculiar is going on in the microscopic field. Something is happening which is foreign to our ordinary experience.

Technically this phenomenon is known as pair production by a photon. The reverse process, conversion of matter into radiation, can occur when an electron and a positron come together under proper conditions. They disappear and two photons of radiation are shot out with the speed of light in opposite directions.

Matter and energy can now be thought of as practically synonymous. It thus becomes possible to make certain grand inferences with the object of saving the universe from running down. Millions of suns are slowly but surely converting their matter and their energy into radiation and this radiation is constantly escaping into infinity. Perhaps somewhere in space radiation may be changed back into matter. Perhaps the universe is engaged in a reversible cycle, instead of an irreversible one, as is commonly supposed.

As an illustration of what Darrow calls an "adventurous excursion" of an observer we may take the Dirac theory of the positron. Dirac is a brilliant young Englishman, a mathematician who has demonstrated a high degree of daring and originality in his handling of theoretical physics.

His theory of the positron starts out with two peculiar assumptions. First, a particle may have a negative kinetic energy. Second, all space is filled with particles of negative kinetic energy. There is a distribution of electrons of infinite density everywhere in the world. A perfect vacuum is a region where all the states of positive energy are unoccupied and all those of negative energy are occupied.

When an electron, by some means or other, gets knocked out of this state of negative energy into a state of positive energy, it is observed as an ordinary electron; the hole which was left is a positron. This hole may wander around for a short time, but there are so many more electrons in the universe than holes that it is not long before some electron drops into the hole and both hole and electron disappear from the view of normal people. The very short life of the positron is thus explained, as is also the phenomenon of pair production and the conversion of matter into radiation.

I have given this hasty outline of the theory, not that I expect anyone to understand it—it is hardly to be expected that negative energy can be understood—but because it illustrates the lengths to which a theorist has to go in creating physical explanation in this field. In the microscopic range of sizes a quite perfect explanation of things is given by a specialized type of mathematics called wave mechanics. It is only when this mathematical symbolism is explained in terms of physical symbolism that we call it an adventurous

excursion. Dirac showed great courage in even trying to give a physical picture of his mathematical theory. The fact is that in the microscopic field things may behave in a way entirely foreign to the way in which we have always seen large objects behave, hence they cannot be explained in the old familiar ways.

There is in most people a strong tendency to label as "bunk" that which is not understood. This tendency is, on the whole, a healthy one. Skepticism is preferable to credulity if one is thinking in terms of the struggle for existence. The radio listeners who believe all the remarkable statements made about cough syrups, breakfast foods, cigarettes, etc., must certainly be struggling very hard for existence. However, skepticism based upon a lack of understanding is a dangerous attitude of mind. Prof. P. W. Bridgman of Harvard has this to say in his book, "The Logic of Modern Physics":

It is difficult to conceive anything more scientifically bigoted than to postulate that all possible experience conforms to the same type as that with which we are already familiar, and therefore to demand that explanations use only elements familiar in everyday experience. Such an attitude bespeaks an unimaginativeness, a mental obtuseness and obstinacy which might be expected to have exhausted their pragmatic justification at a lower plane of mental activity.

The explanation of microscopic phenomena, then, utilizes concepts which are not familiar to everyday experience. For that reason the microscopic tends to undermine any smug complacency we may have regarding our knowledge of nature and the universe. Take, for example, the Heisenberg uncertainty principle. This principle states that we can never know accurately both the position and the velocity of a small particle. It is easy to see why this is true. We can see the small particle because light has bounced off of it into our eye. We see it in the direction from which the light bounced.

But the light, in bouncing from the particle, must have given it a push so that either its position or its velocity will have been changed by the mere fact that light must be used to observe it. By the time the light photon gets to the eye of the observer the particle will not be at exactly the spot from which the photon appeared to bounce.

This uncertainty principle has been given an exact mathematical formulation. It turns out that if the position of an electron is known to within 0.004 inch then the speed of its motion is uncertain to within about 3 feet per second—the speed of a slow walk.

The tendency, at first, is to consider this as rather a superficial principle. I can easily imagine a particle to have both position and momentum simultaneously; why bother so much about a mechanism for determining them? However, a thorough study of the situation, with an analysis of every conceivable means afforded by nature for making determinations, impresses one with a feeling that here is a

conspiracy of nature to prevent man from acquiring too much detailed information. A conspiracy of nature is a law of nature; we cannot pass it over as being of no importance. It is as if nature had erected a wall of impenetrability around the smallest particles and forced us to see them only partially, as if through the cracks in the wall.

It appears, therefore, that we are asking a meaningless question when we ask just where an electron is when it has a certain definite momentum. No possible operation can be thought of by which an answer to this question can be obtained without violating a law of nature. The conclusion is that the electron cannot have an exact velocity and an exact momentum simultaneously. There is an essential fuzziness in the very foundations of nature herself. Time and space are a little peculiar in the microscopic region, most certainly.

Someone has said that "the infinite, whether the infinitely large, or the infinitely small, seems to carry disaster in its wake." I do not think the word disaster is happily chosen in this connection. It is true that the two infinities at either end of our linear lay-out have shattered the beautiful, crystal-clear mechanical system which described the universe during most of the nineteenth century—when the luminiferous ether was as definitely material as a piece of iron, and when a scientist could say that practically all pioneer research in physics was over and nothing remained except to measure things with increasing accuracy. This complacent attitude is fortunately gone forever, and the two infinities have had a great deal to do with its disappearance. The new problems presented, the paradoxes, the uncertainties, all combine to give us a picture of modern science once more struggling, once more growing. It seems better to change the quotation to read, "The infinite, whether the infinitely large or the infinitely small, seems to have carried renaissance in its wake."

In summing up the subject we may say that the small part of the universe, open to everyday experience, has given us a simple conception of nature, a simple body of laws, which seems unable to cope with problems either in the region of the supernebulae or in the region of the extremely small particles.

In the latter field we have found that, properly speaking, descriptions of phenomena must be mainly mathematical. Such descriptions are quite adequate at present, and we feel that the main problems of explanation are well in hand. But we must be careful not to expect the same type of explanation that is used for objects of ordinary size, and we must remember that here there is a certain indefiniteness of behavior. We do not say that a small particle can *never* get over a high hill when it does not have enough energy to carry it to the top. We say that the probability of its getting over is

small. It actually has a small probability of doing the job with an insufficient amount of energy!

In the region of the supernebulae we are at present up against a paradox. We are at liberty to suppose that space is of a peculiarly curved character, or that it goes on to infinity; that the supernebulae are flying away with enormous velocities, or that some unknown principle of nature is deceiving us. We may be affected by a feeling of futility because of this state of affairs, and even have a sympathetic feeling for St. Ambrose, who in A. D. 389 wrote:

To discuss the nature of the earth does not help us in our hope of the life to come. It is enough to know that Scripture states that He hung up the earth on nothing. Why argue whether He hung it up in air or on water? The majesty of God constrains it by the law of His will.

The spirit of modern science is not in agreement with St. Ambrose, and is not to be discouraged by apparent contradictions. This spirit demands continual arguing and speculating as to how the universe is hung up. Certainly we will always see as through a glass darkly, but just as certainly we will always keep on trying to polish the glass.

INDUSTRIAL SCIENCE LOOKS AHEAD¹

BY BRIGADIER GENERAL DAVID SARNOFF

President, Radio Corporation of America

Industrial science at war is shaping a new world. While the battle lines of the United Nations encircle the Fortress Europe and the gigantic pincers of victory tighten on the enemy in the Pacific, civilization advances ever closer to the postwar horizon. With victory will come the day when the scientific instruments and processes of war will turn abruptly to peace. Machines and tools, as well as industrial and economic thinking, will be converted quickly from the demands of war to the needs of peace. Industry will be called upon to relieve the strains of war with utmost speed by ministering anew to human welfare, health, and comfort. Postwar planners are now at work in many fields of industrial endeavor.

It is not new for American industry to be surveying and planning for the future. That process is always at work here, whether the world is at peace or at war. Only by advanced thinking, research, engineering, and continual pioneering, can industrial science put new ideas into action. By doing this, industry serves its workers and the people, and thereby wins the right to survive.

We have but to consider some of the outstanding wartime developments of industrial science to realize their widespread applications in all fields, from automobiles to giant turbines and diesel engines, from cameras to facsimile and television. Endlessly these advances extend into every realm of our daily lives. Among the promises of better living we are told of new plastics, light metals, synthetic textiles, high-octane gasoline, artificial rubber, luminescent lighting, air-conditioning, dehydration of foodstuffs, and many other innovations. We even hear of glass flatirons and plastic lenses. We are promised revolutionary changes in homes, aircraft, communications, ships, railroads, automobiles, highways, clothing, and foods. In myriad ways the wartime inventions in electricity, metallurgy, chemistry, and physics will open new gateways for industrial science to enter and enrich our everyday life.

¹ Address delivered before the Lancaster Chapter of the American Association for the Advancement of Science. Reprinted by permission from *Science*, vol. 98, Nov. 19, 1943.

As for the great, modern art of radio, I can promise you that as a service to mankind everywhere it will keep pace with the march of science and industry in every other field.

Today is the anniversary of a historic event that provides us with a timely opportunity to review the remarkable advances of radio within a quarter century, to reflect upon its vital role in the war, and to look into its future.

Twenty-five years ago this morning, news flashed across the hemispheres that the first World War had ended. In retrospect that day appears as a fleeting moment. History lifted her pen and paused to dot the "i" of an empty victory that proved to be only the prelude to a global war unprecedented in fury, extent, and destruction.

In that autumn of 1918, Germany's pleas for peace had revealed the plight of the German people. Germany was cracking. American radio was entrusted to transmit to a defeated nation President Wilson's Fourteen Points as a basis for the restoration of peace, and for a general armistice on land, on water, and in the air. Radio operators stood by for the answer. It came on the midnight air of November 11, when silence in the "ether" over the Atlantic was interrupted by a flash from Europe. At 2:45 a. m. New York time, the news broke. The State Department in Washington announced the Armistice had been signed at midnight, and hostilities would cease at 6 o'clock in the morning—11 a. m. in France.

There was no radio broadcasting to spread the welcome word—"It's over, over there!"

Under the banner headline "Peace," Americans read the news at their breakfast tables. The world was only a reading world at that time. It had not yet learned to listen. News spread slowly in 1918. Although powerful radio alternators relayed these tidings around the world to ships on the Seven Seas, homes were not yet radio equipped. Many days passed before news of the Armistice filtered into remote hamlets and farms. War correspondents were scribes, not eyewitness broadcasters; they had the pen but no microphone. Today news travels at the speed of light, in every language to every corner of the earth.

In those days there were no globe-encircling short waves, no high-power vacuum tubes, no universal receiving sets. The radiophone was just learning to talk. The electron tube had not yet revealed its power and its unlimited possibilities.

The radio of that day gave everything it had to win the war. Research men and engineers rushed new devices into service to maintain contacts with the battle fleet, with the convoys and the American Expeditionary Force in France. Although ships in the mid-Atlantic could not maintain direct contact with American and European shores,

the long waves of powerful land stations swept across the sea and linked America with its Allies. War bulletins moved through the air at the rate of 30 to 40 words a minute. Today, short waves and high-speed automatic machines handle news at the rate of more than 600 words a minute. In the First World War, American newspapers had to wait for ships to arrive with the historic pictures of Pershing and the A. E. F. in France. Now radiophoto service can deliver pictures of Eisenhower and his forces in Italy and MacArthur and his troops in the South Pacific a few minutes after the camera snaps them.

Today, largely because of radio, New York is the communication center of the world. In 1918, it was London. During the first World War the United States found itself at the mercy of foreign communications. America learned the lesson then, that radio was the nerve system of war as well as of peace. Immediate steps were taken to safeguard the future, to give the United States supremacy in world-wide communications and to make sure that never again would this Republic be dependent upon the wave lengths, cables, or wires operated and controlled by other nations.

As a result of this determination, the direct radiotelegraph circuits of RCA now reach 51 countries in Central and South America, the West Indies, Europe, Asia, Africa, and Australasia. Radiophoto circuits operate between New York and London, Stockholm, Berne, Moscow, Cairo, and Buenos Aires, while the terminal at San Francisco serves Honolulu and Melbourne.

In this war, radio is everywhere—with soldier, sailor, marine, and airman. Modern warfare has put radio instruments into every bomber and fighter plane, into every mechanized unit, and into every ship. There were no walkie-talkies or handy-talkies in No-Man's Land, at Verdun or at the Marne. The "cease firing" order signed by Foch was shouted and carried by runners along the trenches. The radio equipment of that day was too massive and too heavy for more than a limited use in airplanes. Now compact, efficient radio goes aloft with all planes; wave lengths are their life lines. Coordinating great aerial squadrons, radio guides the bombers and swarms of fighters over the targets, and safely back to the airports. The paratrooper leaps from the skies with a miniature radio transmitter—no larger than a cracker box—strapped to his belt. The artillery, through its radio, knows at all times what the infantry wants, when it wants it, and exactly where it wants it.

These historic comparisons dramatize the great advances made by radio in a quarter of a century. Industrial science and private enterprise, free and unfettered, took the war-born electron tubes, the radiotelephone, and the short waves, and adapted them to peaceful pursuits. Clues to what might be accomplished in peace were, how-

ever, in the air during those final months of the first World War. When a sub-chaser dashed out to sea from a port in Maine, its radio operator moved a portable phonograph near to his radiophone microphone to broadcast a popular wartime tune, "I May Be Gone for a Long, Long Time." From the Navy station at New Brunswick, N. J., the "Star Spangled Banner" was broadcast up and down the coast. These were forerunners of the day when radio music from hundreds of stations would encircle the globe.

War had revealed that new instruments could be made available for mass communication. The time was opportune and industrial science was prepared to answer the challenge. Soon after the Armistice, America became aflame with a new national pastime—that of listening-in. The vast industry of broadcasting came into being. Its achievements as a service to America and to all the world during the past quarter of a century are an epoch-making and dramatic story of American ingenuity and enterprise at its best.

In no other nation has radio developed as it has in the United States. Nowhere else are people better informed. Today this country is served by more than 900 broadcasting stations and 4 national networks. There are 60,000,000 receiving sets in our land. The owner of every set is free to listen to any wave length from any country. American radio dials are symbols of freedom.

The scientists, who worked out inventions and harnessed the wave lengths to equip America with this unsurpassed radio system, realized only vaguely that their achievements might be used in a second World War. Theirs were the tasks of peace. They worked to make a symphony orchestra sound with perfection hundreds and thousands of miles distant from its source and enable the human voice to ring true on the other side of the globe.

They extended the influence of news, education, and religion to all parts of the earth. They made the world an open-air theater in which countless millions of people could enjoy free entertainment.

Thus, scientists made American radio the Voice of Freedom, so interwoven with our daily lives that we have come to think of radio as an achievement only of the twentieth century. It is, however, a child of the ages. Modern radio came into existence through a long process of evolution. The long corridors of time through which man has conducted research and experiments extend far into the past. They lead back to ancient Greece. There the first electric sparks, called *electrum*, kindled a new science and unleashed a new force—electricity.

While the men of science were seeking to explain the mystery of these sparks, the philosophers of Greece foresaw that if democratic government were to remain effective, the range of the human voice

would have to be greatly extended. Aristotle argued that the best of states might well outgrow geographical boundaries with populations reaching such size that well-ordered and efficient government could not function. He said that a democratic government required that the citizens keep in touch with one another; that their leaders know each other and that they study at first hand their common political problems and the policies necessary to meet them. But Aristotle warned that it would be impossible to accomplish this in the overgrown state, "for who could be the leader of the people in such a State, or who the town-crier, unless he have the voice of a Stentor?" It would seem that Aristotle even forecast the need for television, because he believed that the people needed to see their leaders, as well as hear them at long range.

Two thousand years later we have seen this come to pass, for science has provided government and its leaders with radio. The entire Nation has become an open forum. The leader of the modern state is heard at one time by more people than Aristotle and Socrates reached in their life time. Electricity has made the microphone the voice of the Stentor; our leaders talk to the people, and at the same instant they are heard around the world.

We of this generation have seen men of evil intent stopped by the very tools of science they perverted ruthlessly to extend their power. We have watched science halt the tyrant and dictator as the stentorian voice of the United Nations cried out in defense of freedom, democracy, and justice.

When this war ends, we shall be on the threshold of a new era in radio—an era in which man will see, as well as hear, distant events. The first two decades of the century belonged to wireless telegraphy. The second two decades featured sound broadcasting; the third two decades promise television. It is not too bold to predict that the fourth two decades will introduce international television with pictures in color.

It is even possible that in the two final decades, we may complete the century with power transmission by radio, and its use in the operation of vehicles, automobiles, ships, railroads, and airplanes. When completed, the story of these first hundred years of radio will make fascinating reading. Even a Jules Verne could not tell us all that lies ahead in this magic realm of radio-electronics.

The science of radio is no longer confined to communications. Among revolutionary accomplishments in other lines, we have the electron microscope, one of the most important new scientific tools of the twentieth century. Developed in RCA Laboratories, and based upon television techniques, this instrument has a high wartime priority rating for use in scientific, medical, and industrial research. For

the first time it has made it possible for us to see and identify molecules, and to photograph the influenza virus. It has revealed, in infinite detail, the true structures of fibers, crystals, and pigments. The submicroscopic world is now opened wide for exploration. Bacteria, tissues, and minute particles of matter have been brought within range of man's eye, for the electron microscope, many times more powerful than the strongest optical microscope, permits magnifications up to 100,000 diameters. A needle on such a scale of magnification would appear as huge as the Washington Monument; a blood corpuscle as large as the wheel of an automobile and a football field five times the size of the United States.

Wartime industrial research and engineering have rushed into use still another branch of radio—the art of utilizing high-frequency radio waves for heating. It violates no military secret to report that in this new field of radiothermics, a laminated airplane propeller can be processed in minutes compared with hours required by ordinary heat and pressure methods. In many cases where uniform heat under accurate control is necessary in industrial processes, radiothermics offers great promise in efficiency and time saving. The wide scope of its application ranges from case-hardening steel to dehydrating foods, from gluing prefabricated houses to seaming thermoplastic materials by means of a "radio sewing machine." These accomplishments are all based upon the simple fact that microwaves, in penetrating an object, encounter resistance and create heat.

Farther afield from communications, research men are exploring supersonic vibrations, far above the range of the human ear. The use of these ultrasonics in chemistry may open a field in which high-intensity sound accelerates chemical reactions. Experiments also indicate important possibilities in many other fields including underwater communication, emulsification of liquids, and precipitation of dust from the air.

We attribute all these lines of progress to the science of electronics. The heart of that science is the radio tube. Millions and millions of radio-electron tubes are on duty around the world. They are being manufactured in the United States at the rate of 400,000 a day. The communities in which they are made are on the front line of production. The great importance of each radio tube that moves off the production lines can only be envisaged by considering the many functions it performs in helping to win the war. The delicate finger of the worker who makes the tubes has a task as vital as the finger of a soldier on the trigger of a rifle.

Likewise, radio-electron tubes are as important in peace as in war. They are the master keys to revolutionary advances in radio. They have registered the sound of footprints in the past; they are the

pulse of the present and the "eye" of television that sees far into the future.

The day may come when every person will have his own little radio station tucked away in his pocket, to hear and to communicate with his home or his office as he walks or rides along the street.

We have much to learn about the microwaves, in which is wrapped up this new world of individualized radio. Tiny electron tubes may make it possible to design radio receivers and transmitters no larger than a fountain pen, a cigarette case, a billfold, or a lady's powder box. Some day people may carry television screens on their wrists as they now carry watches. As the useful spectrum of radio approaches the frontiers of light, the apparatus will become simpler and more compact.

Today science is leading us out of a world in which radio has been blind. Tomorrow we shall have radio sight. By this I do not mean that we shall look only at pictures in motion that travel through the air. Radiovision will have many uses. It will serve wherever sight is needed. For instance, it will be used to prevent collisions on highways and railroads, on sea lanes and on the airways of the world. Radio will be the new eye of transportation and commerce. Applications of radio optics are unlimited. With radio ear and eye to guide them, the great stratoliners will be superhuman in their instincts of hearing and seeing as they speed through space with passengers and freight. Radio, which made the world a whispering gallery, will turn it into a world of mirrors.

Radio's great responsibilities do not stop there. A formidable task lies ahead for communications in the restoration of peace, in the reconstruction of the world, in the reestablishment of international trade.

If American industrial science is to play its destined role in the reconstruction period, government should not unduly restrict private enterprise or enter into competition with industry. On the other hand, it is of no avail for industry merely to point to the dangers of governmental restraints. Industry must give evidence of leadership by presenting practical alternatives.

The day of pioneering in America has not ended. Trail blazing now calls for joint effort by government, labor, and industry. Their authority, experience, and vision must fuse harmoniously to achieve success. The same spirit of give-and-take must prevail in industrial statesmanship as in national and international statesmanship. There must be but one goal—the welfare of the people and the Nation.

Industrial statesmanship can accomplish more than political statesmanship in solving the postwar problems of employment, mass production, prosperity, and the continued uplift of the American standard

of living. Industry can be the great motive power in the solution of these problems. The future of every American home and family depends upon it. Therefore, it is imperative that after victory is achieved on the battlefields, American industry devote the same all-out efforts to the peace that it devoted to the war. There can be no let-down. The problems of peace will be of great magnitude. After the devastation of war, mankind will be called upon to win the peace and to make that peace secure with happiness for all people. If industrial statesmanship fails in this great opportunity, then the approach to the postwar problems necessarily will be political instead of economic.

America's cultivation of science has proved the Nation's salvation in modern warfare. It must not be otherwise in peace. Pioneering and research create wealth and employment.

In considering opportunities for employment after the war we must lift our sights to the skies. Man, long confined in his activities to the surface of the earth and beneath the ground, now finds that the air is a new dimension, offering new adventures and pioneering by a new generation. The air is a universal chemical and physical laboratory in which essential elements for life on earth are created. Nature herself makes unlimited use of celestial space for transmission of light and heat from the sun. Only in recent years has man learned to use the air. Only now is he beginning to discover its tremendous potentialities. Literally out of thin air, chemists are creating new products, physicists are building new services, while man is talking on unseen waves and flying on invisible beams.

On the surface of the earth, ships and railroads, automobiles and industrial machines have created millions of jobs. Underground coal, oil, and minerals provide employment for other millions. Above the earth aviation and radio, electronics and television can open the way for new opportunities in re-employment of war workers and for the millions of men and women who will return from service.

It is estimated that 10,000,000 jobs which did not exist in 1940 must be found to solve the postwar problem of employment. One great hope in helping to meet this unprecedented challenge will be found in the fertile and unexplored frontiers of space. Science, offering new incentives, is beckoning capital to venture into the open skies. We are challenged to look upward to our future.

Horace Greeley, if here today, might say, "Go up, young man, go up and grow up in space." There, lies the unfathomed "West" of this century, with no last frontier; there, lies a vast wilderness rich in resources, opportunities, and adventure. The "Forty-niners" of the present decade will be prospectors in research. They will travel through the air to stake their claims to fame, fortune, and freedom.

To assure the full attainment of these results, private industry and the Government must play their parts with the utmost honesty of purpose, encouraging individual and collective initiative. The national growth of the United States and its contributions through research and invention, are historic proof that traditional American cooperation between industry and government promotes the best public interest.

The role of government in its relationship to labor and industry should be that of an umpire. A wise government does not seek to favor either management or labor. It must be impartial, not partisan.

When the war ends, and we enter the immediate period of transition, the Government in fairness to both labor and industry must readjust its rigid wartime controls. The emergency regulations necessary in wartime, but not necessary in peacetime, should be reduced as speedily as practicable. Elimination of wartime restrictions will enable manufacturers to produce and supply the goods needed by the Nation, to maintain employment, and to adapt new developments in industrial science for the benefit of all people.

America must be practical. Science and industry must have American independence if they are to succeed in the gigantic task of reconversion, re-employment, and world rehabilitation.

Never again can the United States be isolated and secure within its own shores. In the fact that no spot on the globe is farther than 60 hours' flying time from any local airport, is seen the truth that nations must live together as good neighbors. Shriveled by radio and aviation, the new world is a single neighborhood. That is not a theoretical concept. It is a fact.

Today man can travel by train from Chicago to New York in 17 hours; he can fly in 5 hours. He saves 12 hours, but it is of no avail if he does not use that time constructively. If people achieve more leisure, what are they to do with the newly found hours of freedom? This is one of the paramount problems that faces the postwar world. Recreation and entertainment are vital to a happy life. But to be content man must also work. Mere idleness does not produce happiness or progress. Life is measured by time; it is too fleeting and precious to waste.

Entertainment can be as refreshing as sleep. The brain to gain new ideas and to think clearly also must have diversion. In leisure some of the greatest dreams of all time have been born and have grown into revolutionary ideas and inventions. The complete conception of the telegraph flashed into the mind of Morse while on an ocean voyage. The idea of wireless flashed into Marconi's mind while vacationing in the Alps. Great ideas in science, art, and literature seldom come directly to the workbench; they are released at

unsuspecting moments when the subconscious mind has opportunity to come into its own.

In broadcasting we have an outstanding example of an art that is measured by time and linked with opportunity. The listener may use the hours to good advantage, or he may waste them. It is the use to which he puts his radio set and his freedom in selection of programs that reveals the inherent value of broadcasting. The program is the essence. If it brings laughter, if it stimulates thinking, or rests the tired mind, or keeps the listener informed and in touch with his fellowmen, then radio is an antidote for idleness and loneliness.

Science is a mighty ally of freedom—its advance has brought much release from drudgery and from want. However, we must progress still further. For better machines are not all that is needed to make a better life. We shall have a better world only to the extent that our social thinking and our social progress keep pace with the advance of physical science.

We are approaching the days in this struggle when the basic challenge of the postwar years will become sharper and clearer. It is a challenge that will ring out to people in all walks of life, to brains and initiative, to cooperation of government and industry, to labor and management, to religion and education. The answer will be found in the minds and hearts of men and women intent upon preserving civilization and a world at peace.

In this month of Thanksgiving, let us be thankful that America and her Allies have the strength and determination to hold high the eternal torch of freedom. May the victory be a victory of lasting peace, so that out of the bombed and shell-torn earth will come a happier tomorrow for all mankind.

THE NEW MICROSCOPES¹

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[With 5 plates]

It is, to speak conservatively, of extreme interest to review the recent progress made by the scientist in his endeavor to penetrate the unseen world of the minute and disease-causing organisms, in particular a world of viruses—suspected, yet lying just beyond the scope of human vision and the power of the microscope to reveal; for the laboratory research worker, the doctor, the technician long have been familiar with the effects of these unseen enemies they have been called upon to treat and to cope with in man, animal, and plant, and while their knowledge of the infinitesimal has been growing steadily, they were, until very recently, unable to make the slight step “beyond” which would enable them to “see.” But today, science is exploring—looking for the first time upon totally new worlds through the eyes of totally new types of microscopes, microscopes new in principle of construction and in principle of illumination.

THE ELECTRON MICROSCOPE

One of these new instruments, the electron microscope, has received considerable attention and is now being used extensively in both industrial and medical research. Based on the principles of geometric electron optics, this microscope utilizes electrons as a source of illumination instead of the light source of the ordinary light microscope.

Electrons, practically speaking, are the smallest, lightest particles of matter and electricity. Like light, they behave like corpuscles guided by waves. Unlike light, however, they travel in a straight line in a vacuum where, subject to the action of electric and magnetic fields, their behavior coincides with the laws and principles set down by Sir William Hamilton who, more than a century ago, demonstrated the existence of a close analogy between the path of a light ray through refracting media and that of a particle through conservative fields of force.

We know that these negatively charged particles, the electrons, revolving about in their various orbits in the atom, serve to maintain the

¹ Reprinted by permission from the *Journal of the Franklin Institute*, vol. 237, No. 2, February 1944.

balance of the atom while the nucleus exerts the "positive" force which holds it together; and we also know that when this balance is upset, due to gain or loss of electrons, we think of the atom as "charged," since it is this circumstance which causes the tiny particle to attract or repel other electrons according to the state of its unbalance. And science has succeeded in unbalancing the atoms to such an appreciable extent that the negative electricity may be withdrawn and harnessed for use in such instruments as the electron microscopes.

The fact has long been established that atoms are in a constant state of vibration in a heated body and that the greater the heat of the body, the greater the agitation of the atoms. According to the electron theory of metals, electrons circulate about a three-dimensional network, or lattice, of positive ions, some of the electrons being comparatively free, that is to say, the attractions of the ions are practically canceled by the repulsions of the other electrons. It does not necessarily follow, however, that the same electrons consistently remain free. They may be controlled by the ions eventually, but regardless of this, there is always a fixed number of them that are free. Moreover, there is a critical value of speed above which the electrons are able to rise in metals and thus escape from their restraining positive charges, though at ordinary temperatures the proportion of them moving rapidly enough to do this is relatively small. However, as the heat applied to the metal is increased, not only is the thermal agitation of the electrons increased also, but the proportion among them possessing sufficiently high speeds to enable them to leave the metal.

Thus is heat applied to the electron source of the electron microscope which, in the case of most instruments of this kind, is a tungsten filament surrounded by a guard cylinder. After leaving the filament, or cathode, the electrons enter an electric field wherein are large accumulations of charge which serve to speed up steadily the motion of these freely moving particles. Since the electrons travel in vacua, none of the kinetic energy gained in crossing the field is lost, the total kinetic energy, or energy of motion, gained in passing through this region being proportional to the voltage applied. We may deduce, therefore, that since increase of charge in an electric field means a proportional increase of kinetic energy of these electrons, the higher the voltage applied, the greater the speed of the electrons—all of which has been calculated mathematically and confirmed experimentally.

After traversing the electric field and passing through the anode, the electrons are concentrated on the specimen under examination by the first of three magnetic fields which are created by currents flowing through coils enclosed in soft iron shields, molded so as to concentrate

the magnetic fields on a short section of the microscope's axis. Whereas in the ordinary light microscope glass lenses serve as the refractive media through which light rays are deflected, in the electron microscope it is these magnetic fields of rotational symmetry which are the refractive media and serve as the "lenses" which deflect the beams of

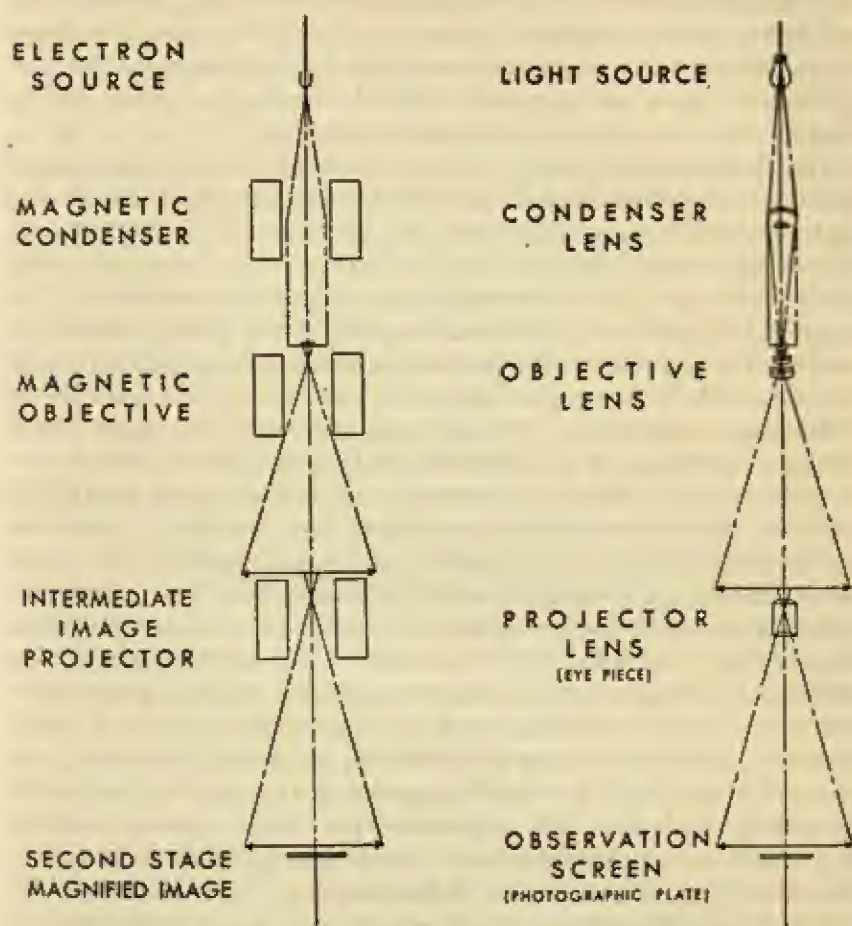


FIGURE 1.—Comparison of a simplified cross section of an electron microscope (left) with that of an ordinary light microscope.

electrons. The first of these, the condenser lens coil, corresponding to the substage condenser of the ordinary light microscope, concentrates the beam of electrons upon the specimen. The convergence of the beam falling on the specimen is controlled by varying the current through this condenser lens. Now, having passed through the specimen, the objective coil, similar in effect to the objective lens, focuses the electrons, and an intermediate image enlarged about 100 diameters

is formed. Finally, the projection coil, corresponding to the projection lens or ocular, produces a further magnified image on a large fluorescent screen. In some of the electron microscopes, there is a periscope-like attachment by means of which it is possible to locate and adjust for study the most interesting portion of the specimen, or that which it is desired should be examined, before the projection lens coil forms the final magnified image upon the screen, since it is sometimes difficult to accomplish this at high magnification. Also, if it is desired that a photographic record be made, the screen can be removed and a photographic plate substituted.

The specimen itself is supported on a thin nitrocellulose membrane less than one-millionth of an inch thick, and clamped in the tip of a cartridge which is inserted between the pole pieces of the objective coil. The membrane is suspended across the opening of a fine-mesh screen, and a plate, serving as the movable stage, supports the cartridge. The image is projected onto the screen according to the density and atomic weight of the specimen. In other words, whereas in the ordinary light microscope the image is seen because of refraction of the specimen or differences in absorption, in the electron microscope the image is seen through scattering of the electrons, and since electrons travel in a straight line in a vacuum, it stands to reason that even a fairly thin specimen will prove sufficient to deflect such particles. Electrons which strike a thick or solid portion of the specimen will, of course, not continue on in a straight line to the screen but will be either completely absorbed by the specimen or scattered too far out of the beam, thus failing to enter the narrow aperture of the objective, so that that portion of the screen corresponding to the thick portion of the specimen will remain dark. However, those electrons which are able to escape complete absorption or too great deflection, because they do not happen to come in contact with too solid a portion of the specimen and either pass along on all sides of it or penetrate the thinner portions where it is possible they may encounter only a single heavy nucleus for considerable scattering (the angle of deflection being proportional to the square root of the thickness), continue on to the screen where they impinge and cause the chemically treated screen to fluoresce, thus providing a study in light and shadow. If the atoms of a particular substance are heavy, they will also deflect more electrons than if they were light. It may be readily seen, therefore, that the thinner the specimen and its mounting, or the greater the variations in density of the specimen, the more internal structure and detail which may be seen, since too great density tends to absorb or interrupt the straight-line progress of too many of the electrons.

Focusing of the image is accomplished by varying the strength of the fields and thereby altering the focal length of the "lens" coils at

will, so that the need of changing the specimen's position in relation to a fixed optical system, as would be the case with an ordinary light microscope, is avoided. Thus, magnification in an electron microscope can be continuously varied.

Some specimens may be mounted directly on the fine-mesh screen while others may be embedded in collodion, sealed between films of collodion, or suspended in a gelatin film, itself supported on collodion film. The supporting films beside being very thin must be homogeneous lest an artifact be created. For the most part, no staining of bacteriological specimens is done since usually they exhibit sufficiently high contrast in density to reveal readily flagella and other detail without any preparation except that of suspending the specimen in distilled water or other liquid and allowing a drop of the suspension to dry on the film surface, which method is also utilized for specimens of colloidal particles, pigments, and other chemical preparations. At times, however, as Dr. L. Marton, of Stanford University, has mentioned in his article on the electron microscope (written for *The Journal of Bacteriology*, March 1941, when he was associated with the R. C. A. Research Laboratories), virus particles may show decided low contrast. One method which Dr. Marton mentioned for overcoming this is to obtain a number of electron micrographs at various focuses and simply select the best one for study. Or the virus may be permitted to absorb colloidal gold which would result in an image of high contrast. Dr. Marton points out that there may be future need for a staining in density and that already osmic acid has been tried and used for this purpose.

In this microscope, voltages of between 30,000 and 60,000 are used. It has been previously stated that the higher the voltage, the greater the speed of the electrons. This might now be augmented to read, the higher the voltage, the greater the speed of electrons; hence, the shorter the wave length. An explanation of this may be approached through a brief discussion of short-wave diffraction as considered by Dr. Karl K. Darrow, of Bell Laboratories, in his book, "The Renaissance of Physics." In order to obtain convenient angles of refraction with the ordinary diffraction grating, it is necessary that the wave lengths of light be smaller, but not many times smaller, than the spacing between the wires or grooves. Naturally, a limit of measurement is reached in the region of ultraviolet light since it is impossible to lessen further the spacing of these gratings. However, this limitation was overcome when von Laue conceived the idea of substituting a crystal for an artificial grating since the atoms in a crystal are a thousand times more closely set together than are the wires or grooves of a grating and are arranged in precise regular order or "lattices," and, like gratings, are unable to diffract waves which are longer than

the spacings between their atoms. Von Laue suggested that if a beam of light were directed across a crystal and made to strike a photographic plate, there would appear a spray of narrow rays each composed of a single wave train instead of the broad fanlike arrangement of the grating, and a pattern of starlike spots where the rays come in contact with the plate instead of the dark irregular blot when a grating is used. Of course, the rays are disposed according to the spacings of the atoms in the lattice and according to the character of the lattice. Von Laue confirmed this idea for waves short enough to be so diffracted and then advanced the theory that this principle might hold true for X-rays as well, which theory was almost immediately confirmed by Friedrich and Knipping. Shortly after Schrodinger began to develop De Broglie's wave theory of electrons, Elsasser conceived the idea that possibly these tiny particles might also be diffracted by crystals, and Doctors Davisson and Germer, of the Bell Telephone Research Laboratories, using as part of their apparatus an electron gun, set out to test and to prove this theory. Due to their experiments and those of G. P. Thomson, it was established beyond a doubt that electron beams are diffracted just as are X-ray beams. However, it was also demonstrated in the course of these experiments that electrons of slow speeds and feeble kinetic energies are unable to penetrate the crystals. It was Thomson who utilized faster electrons and demonstrated that not only are electrons diffracted like X-rays, but like X-rays also they make an imprint upon a photographic plate at increased speeds. These three men, together with others, then measured the wave lengths which they compared with the momenta of these electrons by their diffraction. To these experiments and measurements were then applied the following rules of correlation: "Energy (E) is proportional to frequency (ν), and momentum (p) is inversely proportional to wavelength (λ), the same constant (h) appearing in both relations. (Frequency is interpreted as the velocity (V) of the waves divided by their wavelength.)" These rules can be applied mathematically to the electron microscope to illustrate better the principles of its operation. In making use of the first rule, however, it is necessary to substitute "voltage" for "frequency," and in so doing, therefore, the rules of correlation explain the increase of energy in relation to the increase of voltage as well as the increase of speed of electrons in relation to the decrease or shortening of wave length when we say the higher the voltage, the greater the speed; hence, the shorter the wave length of electrons. It is interesting to note in passing that a 150-volt electron has a wave length of one Angstrom unit, this being more than 10^4 times smaller than the wave length of visible or ultraviolet light.

Because the wave lengths utilized in an electron microscope are so much shorter than those employed in an ordinary light microscope,

it is possible to obtain greatly increased resolution and magnification. As a matter of fact, resolution up to 20,000 or 25,000 diameters may be realized, and increased magnifications beyond this point up to 100,000, even 200,000 diameters, can be obtained, such magnifications, however, constituting enlargement of the image. (Definitions of "resolution" and "magnification" discussed under "The Ordinary Microscope.") This high magnification is greatly desirable since otherwise the eye would be unable to distinguish the fine detail of internal structure at a resolution of the order of 25,000. As a result of this increase in resolution and magnification over that of the ordinary light microscope which is between 1,600 and 2,500 diameters and in the ultramicroscope between 2,500 and 5,000 diameters, many surface cells and much intricate internal structure hitherto unsuspected, or at least undetected by ordinary microscopes, have been revealed. To cite a few examples:

The streptococcal cells appear, not as individual cells, that is, separate and apart from one another, but as chainlike groups, the cells in each chain being bound together apparently by the strong rigid membrane or outer cellular wall which extends over a number of these cells and which is so plainly evident under the electron microscope. Subjected to sonic vibration, these cells suffer a loss of protoplasmic material from their interior, causing them to become mere "ghost" cells, which makes them more transparent to electron beams. That there exists considerable difference between the surface structure and internal composition of these cells has also been determined and demonstrated.

Using the electron microscope, Dr. Harry E. Morton, of the department of bacteriology of the University of Pennsylvania Medical School, and Dr. Thomas F. Anderson, of R. C. A. Research Laboratories were able to demonstrate that in at least one instance where chemical reaction is induced by bacteria this reaction takes place "inside" the cells. The fact that diphtheria bacilli reduce potassium tellurite to metallic tellurium has been known for some time, but whether this reaction occurred inside the cell or on the cell surface or both had never been definitely shown until the electron microscope was made available. Then, obtaining unstained preparations of *Corynebacterium diphtheriae* grown on blood infusion agar, Drs. Morton and Anderson demonstrated that the typical polar granules appear as dense spherical masses, or possibly plates, of a very black color and that in unstained preparations of this same *Corynebacterium diphtheriae* grown on potassium tellurite chocolate agar, not only the polar granules are in evidence but also the tiny needlelike crystals inside the cell which disappear along with the black color of the cell masses when a drop of bromine water is added to 1 cc. of a suspension

of the cells on potassium tellurite chocolate agar. From this the experimenters were able to deduce that tellurium metal occurs in the form of needles and is the cause of the black color, and that this reaction occurs within the cells since the crystals have never been observed to lie totally outside the cell wall, although at times there is some distortion of the wall.

The electron microscope also affords such study and observation as that carried out by Dr. W. M. Stanley, of the Rockefeller Institute of Medical Research, and Dr. Thomas F. Anderson in their recent investigation of plant viruses. By means of electron micrographs, they were able to judge the exact manner and extent of attack made on the tobacco mosaic virus by the protein antibodies in the blood stream of rabbits in which an artificial immunity to the virus had been produced.

Structures like that of the spirochete of Weil's disease, typhoid flagella, unusual internal structure of pertussis organisms, tubercle bacilli, the isolation and recognition of the influenza virus, the spores of trychophyton mentagrophytes, *Spirochaeta pallida* with its accompanying flagellar appendages, and colloidal particles are but a few of the interesting revelations of the electron microscope for medical science. Industrial science, too, has found this new research tool of great value in the study of metals, alloys, and plastics, as well as in the study of size, shape, and distribution of particles in chemical compounds and elements.

The electron microscope herein described is that manufactured by the Radio Corporation of America. There are, of course, variations in construction of the different instruments of this kind but all types are built along similar lines and upon the same general principles. In the electron microscope there is some aberration plus the additional disadvantages of having the specimen in a vacuum, not to mention the probable protoplasmic changes induced by the terrific bombardment of electrons, and finally, what is perhaps the greatest disadvantage insofar as medical science is concerned—that of being unable to view living organisms. Nevertheless, the disadvantages of the microscope are far overshadowed by its increased resolving and magnification powers which have combined to make it an invaluable research tool.

RESOLUTION AND MAGNIFICATION OF ORDINARY MICROSCOPE

We have stated that the resolving power of the ordinary light microscope is restricted to between 1,600 and 2,500 diameters and that of the ordinary ultramicroscope to between 2,500 and 5,000 diameters, resolution in any microscope being the ability of the instrument to reveal the most minute of component parts of a specimen so that each may be seen as a distinct and separate image. For in-

stance, let us suppose an object is examined through which run two very fine parallel lines closely set together. If the two lines are visible under the microscope and are revealed as two separate images, then, apparently, no limit of resolution has been reached; but if the two lines are merged or revealed as only one, and upon further magnification the image merely becomes enlarged without separation of the lines, then a limit of resolution apparently has been reached and additional magnification would constitute only enlargement. Assuming now that the object is a point object in which case the images of the points would be diffraction disks, the disks should likewise be sufficiently resolved so that each may be distinguished as a single image. If, when these disks are seen to overlap, additional magnification fails to extend the distance between them, their size simply increasing in proportion to the increase of magnification, or, if they are all but completely merged and the image becomes just a spurious disk of light, it is evident that a definite limit of resolution has been attained and that further magnification would be useless. Resolution, in a broad sense, then, is the ability of the microscope to bring out or reveal internal structure and detail of a specimen, the shortest distance it is possible to separate two component parts, according to Abbe, being not less than the wave length of light by which the specimen is illuminated divided by the numerical aperture of the objective lens plus the numerical aperture of the condenser lens, or about one-third the wave length of light utilized.

The several factors which are generally acknowledged to be responsible for the limitation of resolving power are interrelated. Now when light passes from one medium into another of different density—in the instance which we are considering that of light refracted by the specimen and passing from air into glass—the light rays are deviated from their straight-line course; that is to say, when they come to within a very short distance of this denser medium, they are acted upon by a very powerful force in such a manner that they execute a short, rapidly curving motion, or an angle, and are pulled into the medium of greater density. When the rays of light undergo such a force, the momentum of the corpuscles is increased and the speed of the waves decreased, resulting, of course, in a shortening of the wave lengths. Here, again, we may make use of the second of the rules of correlation—"Momentum (of corpuscles) varies inversely as wavelength (of waves)." Once well inside the new medium, however, the light rays straighten themselves out again (unless the medium is so constructed that it possesses gradation of density, in which case they follow a curved path). They do this in spite of the fact that the same forces are still acting upon them, although now these forces issue from all sides of them and so cancel each other out, the momentum of the photons or

light corpuscles continuing to increase while the speed of the waves is proportionately retarded. If the light is refracted normally to the surface, however, it does not bend, but tends to cause a shortening of the optical path although the wave length is shortened regardless. It is only when it is refracted obliquely to the surface that the light is bent, the greater the obliquity of the incident ray and the denser the medium, the greater the bending of the angle of the cone of light and the shorter the wave length. It might therefore seem desirable to obtain as great an angle of refraction as possible. However, shortening of the wave length is not in exact proportion to the amount of bending except in the case of the diffraction grating. And regardless of how great a change there is in its angle, the numerical aperture of the light, or angular aperture as it is more properly called, remains constant.

In order, then, that the cone of light be large enough to supply the aperture of the objective with sufficient light to produce an accurate, bright, and enlarged image of the specimen, it is first necessary that the specimen be refracting or emitting light of an adequate quantity, since both magnification and resolution are largely dependent upon the amount of light which the objective utilizes and receives into the tube of the microscope and since such light as the objective does receive should be only that emitted by the specimen. It is obvious, therefore, that it is of primary importance for the specimen itself to be amply illuminated. This would seem to depend entirely on the actual light source, yet no matter how powerful a light source is employed, it is of little avail unless the condenser is of sufficient quality and aperture dimensions to accommodate the light which it receives from the source. If, for instance, the numerical aperture of the objective is 1.25, the width of the cone of light emanating from the specimen should completely fill this aperture in order for the fullest powers of the microscope to be realized. Now, since the condenser supplies the light to the specimen, it stands to reason that it, also, should have a numerical aperture of at least 1.25. However, if the condenser and specimen slide are separated by air, the condenser can provide light of only 1.00 N. A. to the specimen since, according to a law of optics, no aperture greater than 1.00 N. A. (this being the refractive index of air), can pass from a denser medium into air. To remedy this situation, an immersion fluid is placed between the top of the condenser and the lower side of the specimen slide as well as between the specimen and the objective lens.

Since no optical medium has an index of refraction greater than 3 and no immersion fluid an index of refraction greater than 1.7, to increase resolving power further, then, might it not be feasible to widen the apertures of the objective and condenser lenses, thus afford-

ing additional illumination for utilization by both specimen and objective? This idea would be entirely practical except for the fact that such enlargement of the lenses would increase aberration, both spherical and chromatic, and apparently present-day lenses are now as highly corrected as it is possible for human ingenuity and skillful workmanship to make them. Spherical aberration, caused by the paraxial rays coming to a focus at the center of the lens before those rays near the principal axis, is corrected by using concave and convex lenses of different material and, consequently, of different refractive index. In this manner spherical aberration of a convex lens, for instance, can be overcome, without its converging action being altered, by adding to the optical system a concave lens in which there is an equal and opposite aberration. Chromatic aberration, occurring when more than one wave length of light is used to illuminate the specimen, is due to the fact that the shortest waves of the spectrum are refracted most and the longest waves least, thus causing the blue-violet waves to come to a focus ahead of the red waves and resulting in a series of colored foci all along the axis. Now since, as we have said, the shortening of the different groups of wave lengths is not in exact proportion to their bending and since this circumstance varies according to the substance the light rays pass through, it is possible to combine lenses or lens systems in such a way that white light may be obtained. For instance, a small concave flint-glass prism produces the same amount of dispersion as a large convex crown-glass prism. Thus, if these two prisms are placed with their edges opposite, the crown glass will bring together the spectrum produced by the flint glass and white light will be the result. However, the rays of white light will not extend parallel with the original direction but will bend toward the base of the crown glass since the mean refraction of the crown glass is greater than that of the flint glass. Achromatic objectives, corrected spherically for one color, chromatically for two; semiapochromatic objectives, possessing moderate refractive indices and very small dispersion, in which a lens of fluorite is substituted for one of the glass lenses; apochromatic objectives, corrected spherically for two colors, chromatically for three; and also certain monochromatic lenses for use with light of one wave length only are available for overcoming, at least in part, one of the conditions which tends to interfere with better resolution. Condensers, also, can be corrected for both spherical and chromatic aberration and must be achromatic-aplanatic if the light which enters the objective is to come only from the specimen, for condensers with spherical and chromatic aberration are unable to direct their entire cone of light upon the specimen.

In addition to being as highly corrected as possible and possessing a large numerical aperture, an objective should also be capable of ade-

quately magnifying the image, being aided in this by the ocular which also serves at times to compensate for the defects in chromatic magnification which cannot be managed conveniently by high-power objectives, the magnification of the final image being the product of the magnification of the objective multiplied by the magnification of the ocular. An amplifier is sometimes inserted between the objective and ocular which causes the rays of light from the objective to diverge to a greater extent, thus doubling the size of the image. Magnification may also be improved by increasing the tube length, by increasing the distance from which the image is projected, and by altering the positions of the various lenses in an adjustable objective. In general, the greater the magnification, the smaller will be the specimen field, but, as has been stressed, high powers of magnification should always be accompanied by equally high powers of resolution.

As we have seen, resolution in the ordinary light microscope is definitely restricted by a number of interrelated elements. Even when monochromatic light is employed, there is always present some spherical aberration with which to contend. True, better visibility of specimens is provided by dark-field microscopy in which the specimen is viewed by the high contrast of its own scattered or reflected light against a dark field, although in this type of illumination objects in the field must be well separated. Much fine detail and brilliant color of specimens can be observed by means of the polarization of light. Further, it is possible to illuminate the specimen with shorter and shorter wave lengths of light, the shorter the wave length of light used, the more of the fine detail of the specimen which can be seen, but a limit is reached here, also, for ordinary glass lenses are not transparent to ultraviolet rays. However, in the ultraviolet microscope, having a resolution twice that of the instruments using "visible light," the condenser, objective, and ocular are all made of quartz and, by substituting the photographic plate for direct observation, many excellent micrographs of numerous varieties of organisms and cellular structures can be made. But when viewed directly, nothing of the nature or structure of the specimen can be ascertained; only the light scattered by the specimen is distinguishable, the size of the specimen being roughly estimated by the amount of light refracted.

These seemingly unsurmountable obstacles of the ordinary microscopes would appear to indicate that Abbe's law and the contention of physicists that "any object which is smaller than one-half the wave length of light by which it is illuminated cannot be seen in its true form or detail" are destined to remain undefined.

REDUCTION IN THEORETICAL LIMIT OF RESOLUTION DEMONSTRATED

But Dr. Francis F. Lucas, of the Bell Telephone Research Laboratories, and Drs. Louis Caryl Graton and E. C. Dane, Jr., of the depart-

ment of geology, Harvard University, have very convincingly demonstrated a reduction in these theoretical limits of resolution and visibility with their instruments, designed for use in the visible light region of the spectrum.

The Graton-Dane microscope is mounted on a 360-kg. steel foundation bed which, in turn, is supported by six rubber-in-sheer marine-engine mountings—this for the purpose of eliminating all vibration and insuring stability of parts, two factors upon which both men have laid great stress. Any type source, such as the carbon arc, metallic arc, incandescent filament, Point-O-Lite, mercury vapor, or any of the special forms of monochromators, can be used for illuminating the specimen with direct and dark-field transmitted, vertical and oblique reflected, or polarized light. The image beam itself follows a straight-line path in passing from the objective, the objective ranging anywhere from the shortest to the greatest in working distance, through the tube to the ocular, as few lenses as possible being placed in its way. The spiral-cut rack and pinion which moves the stage and substage assembly in longitudinal tracks or guides can be operated by hand or by an electric motor and is independent of the fine adjustment, also motor-driven, which moves only the objective and the carriage carrying the objective. Whereas manual operation of the fine adjustment which is 100 times more sensitive than that of the ordinary instruments necessitates 500 turns of the knob to move the objective a distance of but 1 millimeter (an adjustment calculated to require a time period of 25 minutes), by means of the motor it is possible to move the objective at the rate of 0.01 mm. per second or 0.004 mm. per second, depending upon which of the two speeds is desired, rapid motion being used when the image appears considerably out of focus and decreased speed being used when the image seems to be reaching a point of perfection.²

Resolution up to 6,000 diameters and magnification up to 50,000 diameters have been achieved with this high-precision microscope which photographs or enables observation of both opaque and transparent preparations; in fact, polishing scratches measuring in width but one-tenth the wave length of light used have been clearly distin-

² The mechanism governing the fine adjustment was completely redesigned after it was discovered that changes in the lubricant, used for gear threads and carriage bearings, seriously affected the precision of the instrument. Using a principle suggested to him by R. W. Vose, formerly of the Harvard Engineering School, Dr. Dane built and assembled a new fine-adjustment drive so designed that, as Dr. Graton describes it, "all that part of the mechanism which actuates the slowest, and therefore the most sensitive, part of the motion operates not through gears or screws, but through the differential flexing of a train of spring-bronze strips, which have the double advantage of avoiding all chance for play or backlash and of needing no lubrication whatever. Interferometer tests with the new element in place give practically ideal readings as compared with the theoretical: the deviations are very much smaller than those recorded in our original paper, page 872. The operation of the fine-focusing mechanism selectively by hand knob or by motor-drive, and the slowness of motion, and hence the precise control over focus are the same in the new design as in the old."

guished. It is the opinion of both Dr. Graton and Dr. Dane that some present-day lenses are really capable of better resolution than claimed for them by their manufacturers, it having been their experience to use objectives exhibiting superior qualities of resolution over those of identical medium and numerical aperture, proving that not only have already available lenses surpassed their theoretical limits of resolution, indicating that it might be possible to design objectives with still greater numerical apertures, but that the accepted theory regarding this resolution is sadly in need of revision. Dr. Lucas's microscope utilizing an objective with a numerical aperture of 1.60, for instance, in combination with monobromnaphthalene immersion fluid, also yields resolution up to 6,000 diameters being, like the Graton-Dane scope, a high-precision instrument constructed with the idea of maintaining absolute stability of parts. Dr. Lucas also has expressed doubt as to the complete validity of the generally accepted theory of resolution.

In working with a high-precision ultraviolet microcamera, into which a tricolor filter system has been incorporated, which he has just recently perfected, Dr. Lucas is able to obtain a minimum magnification of 30,000 diameters and a maximum magnification of 60,000 diameters. With this instrument it is possible to view living cells and organisms, no staining or killing of organisms being necessary, and Dr. Lucas has succeeded in obtaining excellent photomicrographs (both still and motion pictures). Of special significance to industry, for instance, is the ability of this scope to demonstrate the size, shape, and reactions in motion and affinity of the tiny particles of which rubber is composed under varying conditions of temperature, etc., while its ability to reveal living rat and mouse sarcoma and carcinoma cells and to demonstrate the development and behavior of the syphilitic organism is of far more than average interest to medical science.

England's Dr. J. E. Barnard has succeeded in obtaining resolution up to 7,500 diameters with his ultra-dark-field scope in which he uses a combined illuminator. In this, an outer system of glass acts as the immersion dark-field illuminator while the inner immersion system of quartz makes possible the passage of a transmitted beam of light through the specimen. Both condensers have the same focus, one for visible light, the other for ultraviolet radiation, and both can be stopped out at will. When, for instance, bacteria are being observed, immersion contact is made between the condenser and quartz slide, the dark-field illuminator being used, thus revealing the bacteria with visible light. When the dark-field illuminator is closed, however, a beam of ultraviolet light may be directed up through the quartz condenser and focused on the bacteria. The object-glass, of course, has to be adjusted since it does not possess the same focus for ultraviolet

that it does for visible light. Staining of specimens is thus unnecessary, making it possible to secure photomicrographs of living minute organisms.

In addition to these four microscopes, a fourth, belonging to the Canadian Department of Mines and located at Ottawa, and almost identical in principle and construction to that of Drs. Dane and Graton, has demonstrated ability to attain equally high resolution. This, like the scopes of Drs. Dane, Graton, and Lucas, is fitted with a tube for visual observation although intended mainly for microphotographical work in the field of metallurgy. It is Dr. Graton's belief, however, that his instrument and that of Dr. Dane might also be adaptable to the purposes of biological research. Referring, in the description of their "Precision, All Purpose Micro-camera" (*Journ. Opt. Soc. Amer.*), to the necessity or "desirability" of "reëxamining the classical conception of the limit of useful magnification," Drs. Dane and Graton have this to say:

So long as the makers accepted the conventional limit as valid and had already attained it, there was little incentive toward progress. But with that limit apparently surpassed, there is no present knowledge as to how far ahead the true limit may lie. If present-day objectives do substantially better than the "limit" for which they were designed, is it not reasonable to suppose that effort to do better still may conceivably be rewarded?

To such an inquiry there can be but one logical answer—an agreement which, while perhaps not concurred in by all, must, for those stimulated to more intense interest and effort by the possibilities of uncovering new facts, pose further questions; for, if the improvement of one part results in the improved performance of the whole, is it not also reasonable to suppose that additional changes of additional parts, yes, even changes with respect to principle and method might likewise bear fruit?

THE UNIVERSAL MICROSCOPE

It is not only a reasonable supposition, but already, in one instance, a very successful and highly commendable achievement on the part of Dr. Royal Raymond Rife of San Diego, Calif., who, for many years, has built and worked with light microscopes which far surpass the theoretical limitations of the ordinary variety of instrument, all the Rife scopes possessing superior ability to attain high magnification with accompanying high resolution. The largest and most powerful of these, the universal microscope, developed in 1933, consists of 5,682 parts and is so called because of its adaptability in all fields of microscopical work, being fully equipped with separate substage condenser units for transmitted and monochromatic beam, dark-field, polarized, and slit-ultra illumination, including also a special device for crystallography. The entire optical system of lenses and prisms as well as

the illuminating units are made of block-crystal quartz, quartz being especially transparent to ultraviolet radiations.

The illuminating unit used for examining the filterable forms of disease organisms contains 14 lenses and prisms, 3 of which are in the high-intensity incandescent lamp, 4 in the Risley prism, and 7 in the achromatic condenser which, incidentally, has a numerical aperture of 1.40. Between the source of light and the specimen are subtended two circular, wedge-shaped, block-crystal quartz prisms for the purpose of polarizing the light passing through the specimen, polarization being the practical application of the theory that light waves vibrate in all planes perpendicular to the direction in which they are propagated. Therefore, when light comes into contact with a polarizing prism, it is divided or split into two beams, one of which is refracted to such an extent that it is reflected to the side of the prism without, of course, passing through the prism while the second ray, bent considerably less, is thus enabled to pass through the prism to illuminate the specimen. When the quartz prisms on the universal microscope, which may be rotated with vernier control through 360° , are rotated in opposite directions, they serve to bend the transmitted beams of light at variable angles of incidence while, at the same time, a spectrum is projected up into the axis of the microscope, or rather a small portion of a spectrum since only a part of a band of color is visible at any one time. However, it is possible to proceed in this way from one end of the spectrum to the other, going all the way from the infrared to the ultraviolet. Now, when that portion of the spectrum is reached in which both the organism and the color band vibrate in exact accord, one with the other, a definite characteristic spectrum is emitted by the organism. In the case of the filter-passing form of the *Bacillus typhosus*, for instance, a blue spectrum is emitted and the plane of polarization deviated plus 4.8° . The predominating chemical constituents of the organism are next ascertained after which the quartz prisms are adjusted or set, by means of vernier control, to minus 4.8° (again in the case of the filter-passing form of the *Bacillus typhosus*) so that the opposite angle of refraction may be obtained. A monochromatic beam of light, corresponding exactly to the frequency of the organism (for Dr. Rife has found that each disease organism responds to and has a definite and distinct wave length, a fact confirmed by British medical research workers) is then sent up through the specimen and the direct transmitted light, thus enabling the observer to view the organism stained in its true chemical color and revealing its own individual structure in a field which is brilliant with light.

The objectives used on the universal microscope are a 1.12 dry lens, a 1.16 water immersion, a 1.18 oil immersion, and a 1.25 oil immersion. The rays of light refracted by the specimen enter the objective and are

then carried up the tube in parallel rays through 21 light bends to the ocular, a tolerance of less than one wave length of visible light only being permitted in the core beam, or chief ray, of illumination. Now, instead of the light rays starting up the tube in a parallel fashion, tending to converge as they rise higher and finally crossing each other, arriving at the ocular separated by considerable distance as would be the case with an ordinary microscope, in the universal tube the rays also start their rise parallel to each other but, just as they are about to cross, a specially designed quartz prism is inserted which serves to pull them out parallel again, another prism being inserted each time the rays are about ready to cross. These prisms, inserted in the tube, which are adjusted and held in alignment by micrometer screws of 100 threads to the inch in special tracks made of magnesium (magnesium having the closest coefficient of expansion of any metal to quartz), are separated by a distance of only 30 millimeters. Thus, the greatest distance that the image in the universal is projected through any one media, either quartz or air, is 30 millimeters instead of the 160, 180, or 190 millimeters as in the empty or air-filled tube of an ordinary microscope, the total distance which the light rays travel zigzag fashion through the universal tube being 449 millimeters, although the physical length of the tube itself is 229 millimeters. It will be recalled that if one pierces a black strip of paper or cardboard with the point of a needle and then brings the card up close to the eye so that the hole is in the optic axis, a small brilliantly lighted object will appear larger and clearer, revealing more fine detail, than if it were viewed from the same distance without the assistance of the card. This is explained by the fact that the beam of light passing through the card is very narrow, the rays entering the eye, therefore, being practically parallel, whereas without the card the beam of light is much wider and the diffusion circles much larger. It is this principle of parallel rays in the universal microscope and the resultant shortening of projection distance between any two blocks or prisms plus the fact that objectives can thus be substituted for oculars, these "oculars" being three matched pairs of 10-millimeter, 7-millimeter, and 4-millimeter objectives in short mounts, which make possible not only the unusually high magnification and resolution but which serve to eliminate all distortion as well as all chromatic and spherical aberration.

Quartz slides with especially thin quartz cover glasses are used when a tissue section or culture slant is examined, the tissue section itself also being very thin. An additional observational tube and ocular which yield a magnification of 1,800 diameters are provided so that that portion of the specimen which it is desired should be examined may be located and so that the observer can adjust himself more readily when viewing a section at a high magnification.

The universal stage is a double rotating stage graduated through 360° in quarter-minute arc divisions, the upper segment carrying the mechanical stage having a movement of 40°, the body assembly which can be moved horizontally over the condenser also having an angular tilt of 40° plus or minus. Heavily constructed joints and screw adjustments maintain rigidity of the microscope which weighs 200 pounds and stands 24 inches high, the bases of the scope being nickel cast-steel plates, accurately surfaced, and equipped with three leveling screws and two spirit levels set at angles of 90°. The coarse adjustment, a block thread screw with 40 threads to the inch, slides in a 1½ dovetail which gibs directly onto the pillar post. The weight of the quadruple nosepiece and the objective system is taken care of by the intermediate adjustment at the top of the body tube. The stage, in conjunction with a hydraulic lift, acts as a lever in operating the fine adjustment. A 6-gauge screw having 100 threads to the inch is worked through a gland into a hollow, glycerine-filled post, the glycerine being displaced and replaced at will as the screw is turned clockwise or anticlockwise, allowing a 5-to-1 ratio on the lead screw. This, accordingly, assures complete absence of drag and inertia. The fine adjustment being 700 times more sensitive than that of ordinary microscopes, the length of time required to focus the universal ranges up to 1½ hours which, while on first consideration, may seem a disadvantage, is after all but a slight inconvenience when compared with the many years of research and the hundreds of thousands of dollars spent and being spent in an effort to isolate and to look upon disease-causing organisms in their true form.

Working together back in 1931 and using one of the smaller Rife microscopes having a magnification and resolution of 17,000 diameters, Dr. Rife and Dr. Arthur Isaac Kendall, of the department of bacteriology of Northwestern University Medical School, were able to observe and demonstrate the presence of the filter-passing forms of *Bacillus typhosus*. An agar slant culture of the Rawlings strain of *Bacillus typhosus* was first prepared by Dr. Kendall and inoculated into 6 cc. of "Kendall" K Medium, a medium rich in protein but poor in peptone and consisting of 100 mg. of dried hog intestine and 6 cc. of tyrode solution (containing neither glucose nor glycerine) which mixture is shaken well so as to moisten the dried intestine powder and then sterilized in the autoclave, 15 pounds for 15 minutes, alterations of the medium being frequently necessary depending upon the requirements for different organisms. Now, after a period of 18 hours in this K Medium, the culture was passed through a Berkefeld "N" filter, a drop of the filtrate being added to another 6 cc. of K Medium and incubated at 37° C. Forty-eight hours later this same process was repeated, the "N" filter again being used, after which it was noted

that the culture no longer responded to peptone medium, growing now only in the protein medium. When again, within 24 hours, the culture was passed through a filter—the finest Berkefeld “W” filter, a drop of the filtrate was once more added to 6 cc. of K Medium and incubated at 37° C., a period of 3 days elapsing before the culture was transferred to K Medium and yet another 3 days before a new culture was prepared. Then, viewed under an ordinary microscope, these cultures were observed to be turbid and to reveal no bacilli whatsoever. When viewed by means of dark-field illumination and oil-immersion lens, however, the presence of small, actively motile granules was established, although nothing at all of their individual structure could be ascertained. Another period of 4 days was allowed to elapse before these cultures were transferred to K Medium and incubated at 37° C. for 24 hours when they were then examined under the Rife microscope where, as was mentioned earlier, the filterable typhoid bacilli, emitting a blue spectrum, caused the plane of polarization to be deviated plus 4.8°. Then when the opposite angle of refraction was obtained by means of adjusting the polarizing prisms to minus 4.8° and the cultures illuminated by a monochromatic beam coordinated in frequency with the chemical constituents of the typhoid bacillus, small, oval, actively motile, bright turquoise-blue bodies were observed at a magnification of 5,000 diameters, in high contrast to the colorless and motionless debris of the medium. These observations were repeated eight times, the complete absence of these bodies in uninoculated control K Media also being noted.

To further confirm their findings, Drs. Rife and Kendall next examined 18-hour-old cultures which had been inoculated into K Medium and incubated at 37° C., since it is just at this stage of growth in this medium and at this temperature that the cultures become filterable. And, just as had been anticipated, ordinary dark-field examination revealed unchanged, long, actively motile bacilli; bacilli having granules within their substance; and free-swimming, actively motile granules; while under the Rife microscope were demonstrated the same long, unchanged, almost colorless bacilli; bacilli, practically colorless, inside and at one end of which was a turquoise-blue granule resembling the filterable forms of the typhoid bacillus; and free-swimming, small, oval, actively motile, turquoise-blue granules. By transplanting the cultures of the filter-passing organisms or virus into a broth, they were seen to change over again into their original rodlike forms.

At the same time that these findings of Drs. Rife and Kendall were confirmed by Dr. Edward C. Rosenow, of the Mayo Foundation, the magnification with accompanying resolution of 8,000 diameters of the Rife microscope, operated by Dr. Rife, was checked against a dark-

field oil-immersion scope operated by Dr. Kendall and an ordinary 2-mm. oil-immersion objective, $\times 10$ ocular, Zeiss scope operated by Dr. Rosenow at a magnification of 900 diameters. Examinations of gram- and safranin-stained films of cultures of *Bacillus typhosus*, gram- and safranin-stained films of cultures of the streptococcus from poliomyelitis, and stained films of blood and of the sediment of the spinal fluid from a case of acute poliomyelitis were made with the result that bacilli, streptococci, erythrocytes, polymorphonuclear leukocytes, and lymphocytes measuring nine times the diameter of the same specimens observed under the Zeiss scope at a magnification and resolution of 900 diameters, were revealed with unusual clarity. Seen under the dark-field microscope were moving bodies presumed to be the filterable turquoise-blue bodies of the typhoid bacillus which, as Dr. Rosenow has declared in his report (Observations on filter-passing forms of *Eberthella typhi*—*Bacillus typhosus*—and of the streptococcus from poliomyelitis, Proc. Staff Meetings Mayo Clinic, July 13, 1932), were so "unmistakably demonstrated" with the Rife microscope, while under the Zeiss scope stained and hanging-drop preparations of clouded filtrate cultures were found to be uniformly negative. With the Rife microscope also were demonstrated brownish-gray cocci and diplococci in hanging-drop preparations of the filtrates of streptococcus from poliomyelitis. These cocci and diplococci, similar in size and shape to those seen in the cultures although of more uniform intensity, and characteristic of the medium in which they had been cultivated, were surrounded by a clear halo about twice the width of that at the margins of the debris and of the *Bacillus typhosus*. Stained films of filtrates and filtrate sediments examined under the Zeiss microscope, and hanging-drop, dark-field preparations revealed no organisms, however. Brownish-gray cocci and diplococci of the exact same size and density as those observed in the filtrates of the streptococcus cultures were also revealed in hanging-drop preparations of the virus of poliomyelitis under the Rife microscope, while no organisms at all could be seen in either the stained films of filtrates and filtrate sediments examined with the Zeiss scope or in hanging-drop preparations examined by means of the dark-field. Again using the Rife microscope at a magnification of 8,000 diameters, numerous nonmotile cocci and diplococci of a bright-to-pale pink in color were seen in hanging-drop preparations of filtrates of Herpes encephalitic virus. Although these were observed to be comparatively smaller than the cocci and diplococci of the streptococcus and poliomyelitic viruses, they were shown to be of fairly even density, size, and form and surrounded by a halo. Again, both the dark-field and Zeiss scopes failed to reveal any organisms, and none of the three microscopes disclosed the

presence of such diplococci in hanging-drop preparations of the filtrate of a normal rabbit brain. Dr. Rosenow has since revealed these organisms with the ordinary microscope at a magnification of 1,000 diameters by means of his special staining method and with the electron microscope at a magnification of 12,000 diameters. Dr. Rosenow has expressed the opinion that the inability to see these and other similarly revealed organisms is due, not necessarily to the minuteness of the organisms, but rather to the fact that they are of a nonstaining, hyaline structure. Results with the Rife microscopes, he thinks, are due to the "ingenious methods employed rather than to excessively high magnification." He has declared also, in the report mentioned previously, that "Examination under the Rife microscope of specimens containing objects visible with the ordinary microscope, leaves no doubt of the accurate visualization of objects or particulate matter by direct observation at the extremely high magnification obtained with this instrument."

Exceedingly high powers of magnification with accompanying high powers of resolution may be realized with all of the Rife microscopes, one of which, having magnification and resolution up to 18,000 diameters, is now being used at the British School of Tropical Medicine in England. In a recent demonstration of another of the smaller Rife scopes (May 16, 1942) before a group of doctors including Dr. J. H. Renner, of Santa Barbara, Calif.; Dr. Roger A. Schmidt, of San Francisco, Calif.; Dr. Lois Bronson Slade, of Alameda, Calif.; Dr. Lucile B. Larkin, of Bellingham, Wash.; Dr. E. F. Larkin, of Bellingham, Wash.; and Dr. W. J. Gier, of San Diego, Calif., a Zeiss ruled grating was examined, first under an ordinary commercial microscope equipped with a 1.8 high dry lens and $\times 10$ ocular, and then under the Rife microscope. Whereas 50 lines were revealed with the commercial instrument and considerable aberration, both chromatic and spherical noted, only 5 lines were seen with the Rife scope, these 5 lines being so highly magnified that they occupied the entire field, without any aberration whatsoever being apparent. Dr. Renner, in a discussion of his observations, stated that "The entire field to its very edges and across the center had a uniform clearness that was *not* true in the conventional instrument." Following the examination of the grating, an ordinary unstained blood film was observed under the same two microscopes. In this instance, 100 cells were seen to spread throughout the field of the commercial instrument while but 10 cells filled the field of the Rife scope.

The universal microscope, of course, is the most powerful Rife scope, possessing a resolution of 31,000 diameters and magnification of 60,000 diameters. With this it is possible to view the interior of the

"pin-point" cells, those cells situated between the normal tissue cells and just visible under the ordinary microscope, and to observe the smaller cells which compose the interior of these pin-point cells. When one of these smaller cells is magnified, still smaller cells are seen within its structure. And when one of the still smaller cells, in its turn, is magnified, it, too, is seen to be composed of smaller cells. Each of the 16 times this process of magnification and resolution can be repeated, it is demonstrated that there are smaller cells within the smaller cells, a fact which amply testifies as to the magnification and resolving power obtainable with the universal microscope.

More than 20,000 laboratory cultures of carcinoma were grown and studied over a period of 7 years by Dr. Rife and his assistants in what, at the time, appeared to be a fruitless effort to isolate the filter-passing form, or virus, which Dr. Rife believed to be present in this condition. Then, in 1932, the reactions in growth of bacterial cultures to light from the rare gasses was observed, indicating a new approach to the problem. Accordingly, blocks of tissue one-half centimeter square, taken from an un ulcerated breast carcinoma, were placed in triple-sterilized K Medium and these cultures incubated at 37° C. When no results were forthcoming, the culture tubes were placed in a circular glass loop filled with argon gas to a pressure of 14 millimeters, and a current of 5,000 volts applied for 24 hours, after which the tubes were placed in a 2-inch water vacuum and incubated at 37° C. for 24 hours. Using a specially designed 1.12 dry lens, equal in amplitude of magnification to the 2-mm. apochromatic oil-immersion lens, the cultures were then examined under the universal microscope, at a magnification of 10,000 diameters, where very much animated, purplish-red, filterable forms, measuring less than one-twentieth of a micron in dimension, were observed. Carried through 14 transplants from K Medium to K Medium, this B. X. virus remained constant; inoculated into 426 Albino rats, tumors "with all the true pathology of neoplastic tissue" were developed. Experiments conducted in the Rife Laboratories have established the fact that these characteristic diplococci are found in the blood monocytes in 92 percent of all cases of neoplastic diseases. It has also been demonstrated that the virus of cancer, like the viruses of other diseases, can be easily changed from one form to another by means of altering the media upon which it is grown. With the first change in media, the B. X. virus becomes considerably enlarged although its purplish-red color remains unchanged. Observation of the organism with an ordinary microscope is made possible by a second alteration of the media. A third change is undergone upon asparagus base media where the B. X. virus is transformed from its filterable state into cryptomyces pleomorphia

fungi, these fungi being identical morphologically both macroscopically and microscopically to that of the orchid and of the mushroom. And yet a fourth change may be said to take place when this cryptomyces pleomorphia, permitted to stand as a stock culture for the period of metastasis, becomes the well-known mahogany-colored *Bacillus coli*.

It is Dr. Rife's belief that all micro-organisms fall into 1 of not more than 10 individual groups (Dr. Rosenow has stated that some of the viruses belong to the group of the streptococcus), and that any alteration of artificial media or slight metabolic variation in tissues will induce an organism of one group to change over into any other organism included in that same group, it being possible, incidentally, to carry such changes in media or tissues to the point where the organisms fail to respond to standard laboratory methods of diagnosis. These changes can be made to take place in as short a period of time as 48 hours. For instance, by altering the media—4 parts per million per volume—the pure culture of mahogany-colored *Bacillus coli* becomes the turquoise-blue *Bacillus typhosus*. Viruses or primordial cells of organisms which would ordinarily require an 8-week incubation period to attain their filterable state, have been shown to produce disease within 3 days' time, proving Dr. Rife's contention that the incubation period of a micro-organism is really only a cycle of reversion. He states:

In reality, it is not the bacteria themselves that produce the disease, but we believe it is the chemical constituents of these micro-organisms enacting upon the unbalanced cell metabolism of the human body that in actuality produce the disease. We also believe if the metabolism of the human body is perfectly balanced or poised, it is susceptible to no disease.

In other words, the human body itself is chemical in nature, being comprised of many chemical elements which provide the media upon which the wealth of bacteria normally present in the human system feed. These bacteria are able to reproduce. They, too, are composed of chemicals. Therefore, if the media upon which they feed, in this instance the chemicals or some portion of the chemicals of the human body, become changed from the normal, it stands to reason that these same bacteria, or at least certain numbers of them, will also undergo a change chemically since they are now feeding upon media which are not normal to them, perhaps being supplied with too much or too little of what they need to maintain a normal existence. They change, passing usually through several stages of growth, emerging finally as some entirely new entity—as different morphologically as are the caterpillar and the butterfly (to use an illustration given us). The majority of the viruses have been definitely revealed as living organisms, foreign organisms it is true, but which once were normal inhab-

itants of the human body—living entities of a chemical nature or composition.

Under the universal microscope disease organisms such as those of tuberculosis, cancer, sarcoma, streptococcus, typhoid, staphylococcus, leprosy, hoof and mouth disease, and others may be observed to succumb when exposed to certain lethal frequencies, coordinated with the particular frequencies peculiar to each individual organism, and directed upon them by rays covering a wide range of waves. By means of a camera attachment and a motion-picture camera not built into the instrument, many "still" micrographs as well as hundreds of feet of motion-picture film bear witness to the complete life cycles of numerous organisms. It should be emphasized, perhaps, that invariably the same organisms refract the same colors when stained by means of the monochromatic beam of illumination on the universal microscope, regardless of the media upon which they are grown. The virus of the *Bacillus typhosus* is always a turquoise blue, the *Bacillus coli* always mahogany colored, the *Mycobacterium leprae* always a ruby shade, the filter-passing form or virus of tuberculosis always an emerald green, the virus of cancer always a purplish red, and so on. Thus, with the aid of this microscope, it is possible to reveal the typhoid organism, for instance, in the blood of a suspected typhoid patient 4 and 5 days before a Widal is positive. When it is desired to observe the flagella of the typhoid organism, Hg salts are used as the medium to see at a magnification of 10,000 diameters.

In the light of the amazing results obtainable with this universal microscope and its smaller brother scopes, there can be no doubt of the ability of these instruments to actually reveal any and all microorganisms according to their individual structure and chemical constituents.

With the aid of its new eyes—the new microscopes, all of which are continually being improved—science has at last penetrated beyond the boundary of accepted theory and into the world of the viruses with the result that we can look forward to discovering new treatments and methods of combating the deadly organisms—for science does not rest.

To Dr. Karl K. Darrow, Dr. John A. Kolmer, Dr. William P. Lang, Dr. L. Marton, Dr. J. H. Renner, Dr. Royal R. Rife, Dr. Edward C. Rosenow, Dr. Arthur W. Yale, and Dr. V. K. Zworykin, we wish to express our appreciation for the help and information so kindly given us and to express our gratitude, also, for the interest shown in this effort of bringing to the attention of more of the medical profession the possibilities offered by the new microscopes.

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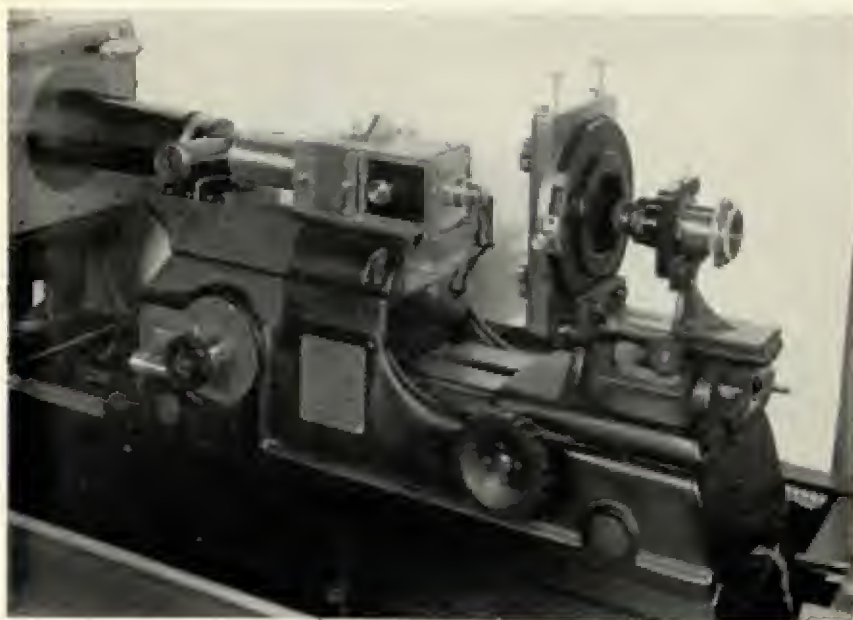




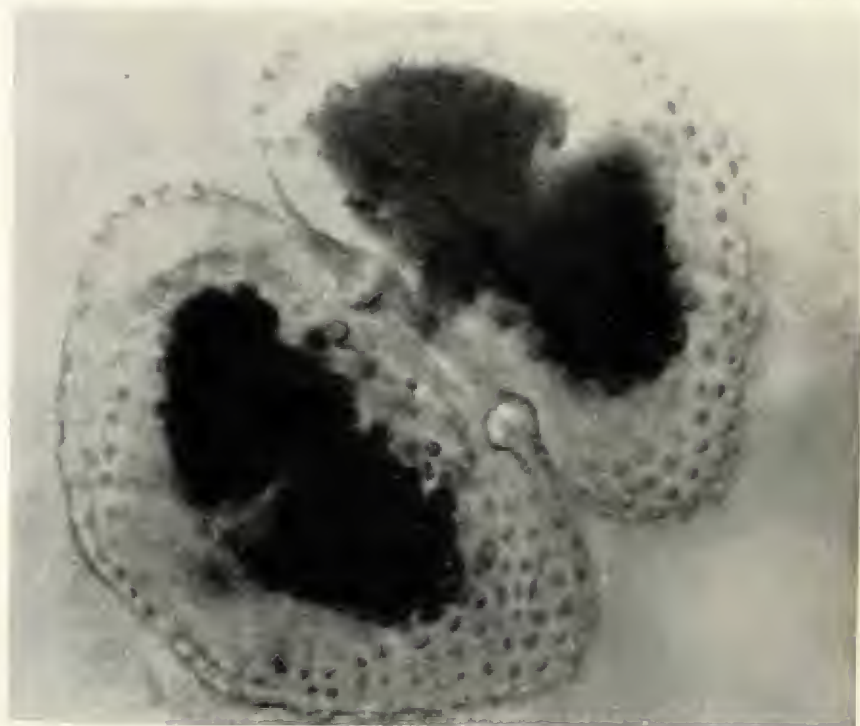
R. C. A. TYPE B ELECTRON MICROSCOPE BESIDE A LABORATORY MODEL OF THE
DESK TYPE ELECTRON MICROSCOPE.



1. GENERAL VIEW OF GRATON-DANE PRECISION, ALL-PURPOSE MICROCAMERA.

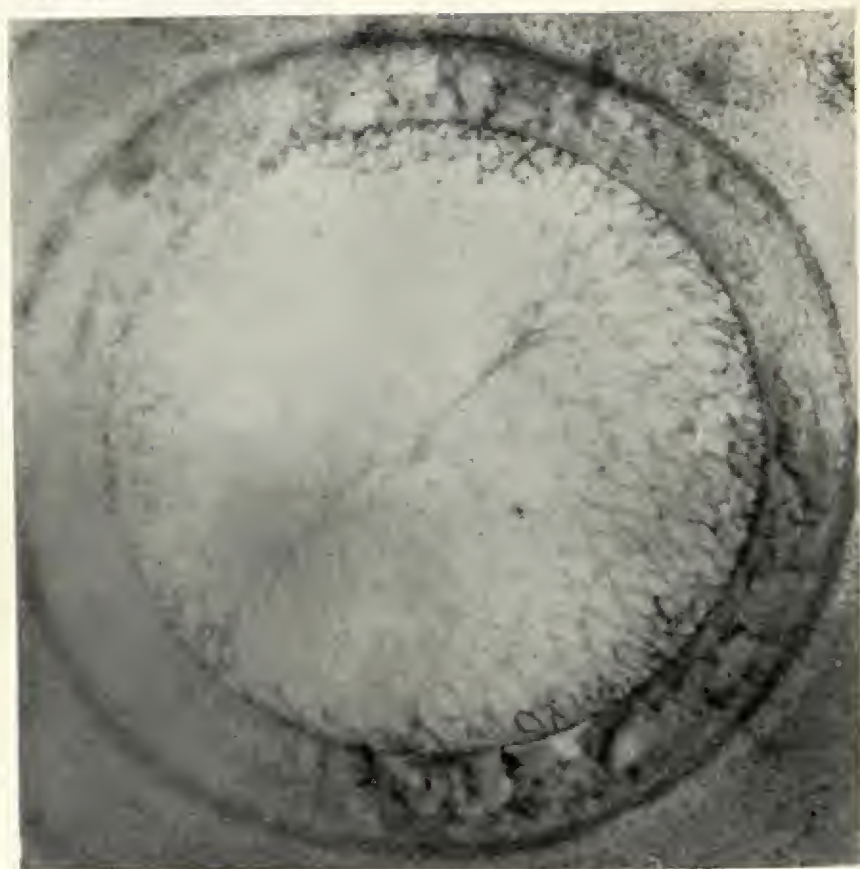


2. CLOSE-RANGE VIEW OF GRATON-DANE PRECISION, ALL-PURPOSE MICROCAMERA.



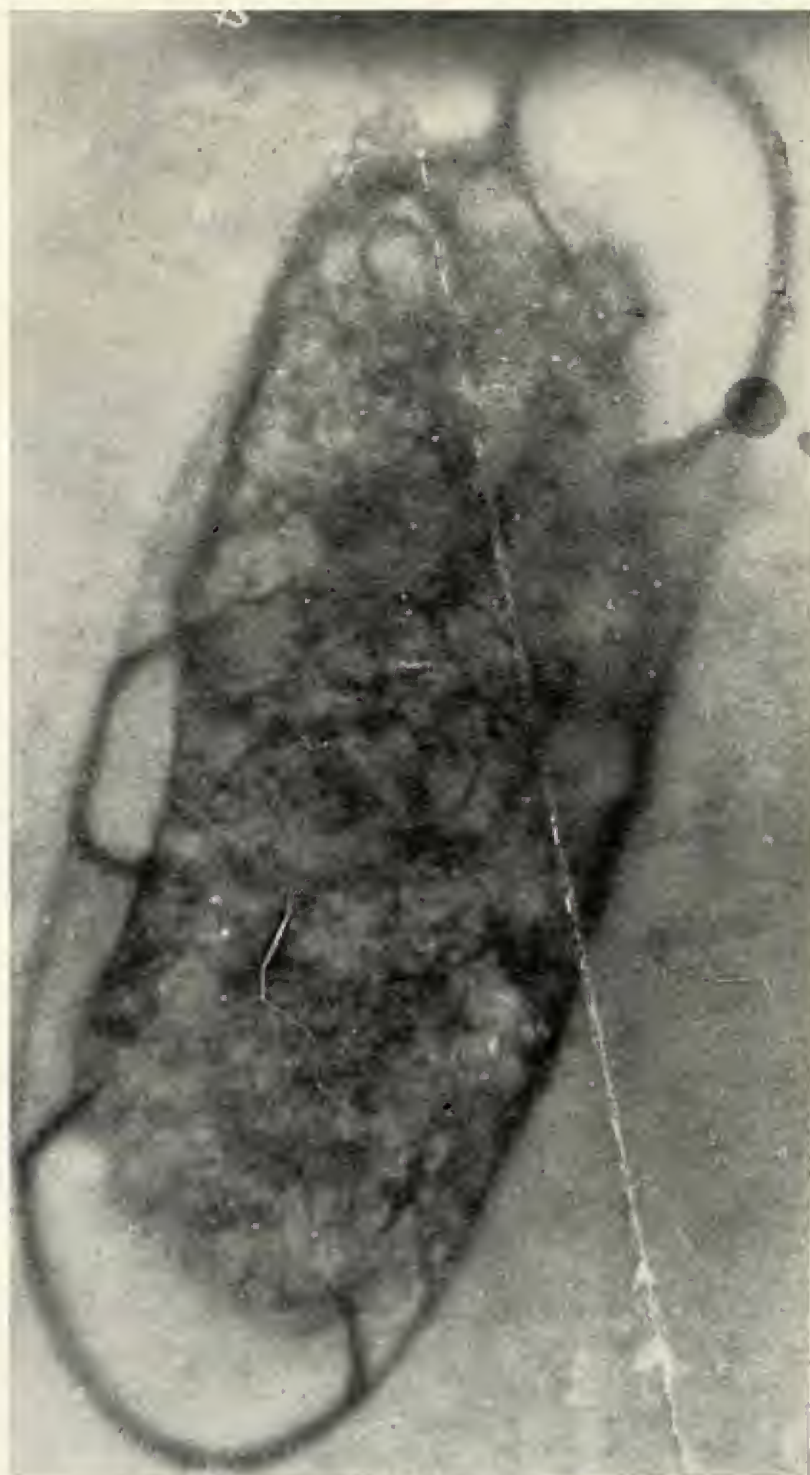
CHLOROPHYL CELLS (ALGAE) (THE UNIVERSAL MICROSCOPE).

17,000 X on 35-mm. film.



TETANUS SPORES (THE UNIVERSAL MICROSCOPE).

25,000 \times on 35-mm. film, enlarged 227,000 \times .



TYPHOID BACILLUS (THE UNIVERSAL MICROSCOPE).

25,000 X on 35-mm. film, enlarged 300,000 X.

RADIO ACOUSTIC RANGING (R. A. R.)

By COMMANDER K. T. ADAMS
United States Coast and Geodetic Survey

[With 1 plate]

Hydrographic surveying consists essentially in measuring water depths from a survey vessel and locating those depths in geographic position or with reference to the adjacent land features. The method almost universally used for fixing hydrographic surveys within sight of land is by measuring two sextant angles to three appropriately located visible control stations. This is the well-known three-point problem. In hydrographic surveying such a position determination is called a three-point fix. The method is sometimes used beyond sight of land, where the depths of the water permit, by utilizing systems of anchored buoys for control stations.

Beyond the limit of visibility of shore objects and where buoys cannot be used, hydrographic surveys were formerly controlled either by dead reckoning or by celestial observations. At considerable distances from the coast and in deep oceanic areas, such methods sufficed, even though both are notably inaccurate as compared with the three-point fix method. However, there was serious need for a more accurate method for use in coastal waters just beyond the range of the three-point fix method. Radio acoustic ranging (R. A. R.) was developed for use in such areas.

HISTORY OF R. A. R.

Subaqueous sound was first used in navigation to determine the direction of an underwater sound source by means of two hydrophones (subaqueous sound receivers) installed on a ship, one on each side near the ship's bow. A patent was granted for this device in 1894. Probably the first practical use of subaqueous sound to determine horizontal distances at sea was by means of a submarine bell suspended below a lightship. Such bells were in general use by the United States Lighthouse Service in 1906. Other experiments were made in connection with the use of subaqueous sound in navigation, but the rapid development of radio direction finding fulfilled the need for position determination in navigation. The sinking of the *Titanic* in

1912 emphasized the need for a means to detect icebergs in the track of a vessel and led to experiments in the use of subaqueous sound for this purpose. The instruments and methods developed, however, found their greatest application in measuring depths of water by subaqueous sound, resulting in modern echo sounding.

During World War I the transmission of sound in sea water was intensively studied by the world's foremost scientists in combatting the submarine menace. As a result, instrumental equipment for transmitting and receiving subaqueous sound was perfected, as well as instruments specifically designed for the measurement of sound travel. After World War I, the Coast and Geodetic Survey became interested in the possible use of the method to control hydrographic surveys. In collaboration with the War Department and the Bureau of Standards, experiments were conducted in the further development of the method and in the redesign of instrumental equipment. The method was first actually used in hydrographic surveying on the ship *Guide* off the coast of southern California in early 1924. It was an immediate success, although many details of procedure had to be perfected before it could be used with assurance.

THEORY

In radio acoustic ranging the position of a subaqueous sound source is determined with reference to two or more appropriately located sound receivers whose positions are known. Such a use of sound has also been called "phonotelemetry." Angles are not utilized in this procedure—the unknown position is determined by measuring the travel times of the sound from its source to the sound receivers. If the effective horizontal velocity of sound in sea water is known, the distances from the sound source to the receiving stations may be determined by multiplying the travel times by the velocity, and from the distances the position of the sound source may be found.

There are several ways in which the travel time of subaqueous sound can be used to determine the position of an unknown point:

(a) Three or more appropriately located receiving units may be interconnected electrically or by radio and the times of arrival of the subaqueous sound at the several stations may be recorded at a central station. Knowing the velocity of sound, the differences between the arrival times may be used to derive the position of the source of the sound. This is known as the "differential method" and it is in general military use to determine the positions of enemy gun emplacements.

(b) The subaqueous sound impulse may be synchronized at the source with a radio signal. If the elapsed times between the receipt of the radio signal and the receipt of the subaqueous sound are

observed at two or more receiving stations at known positions, these time intervals may be used to determine the position of the sound source.

(c) All operations may be controlled and all measurements made at the sound source. A subaqueous sound signal is made near a survey vessel and its time recorded. The instants of arrival of the subaqueous sound at two or more receiving stations are then signaled

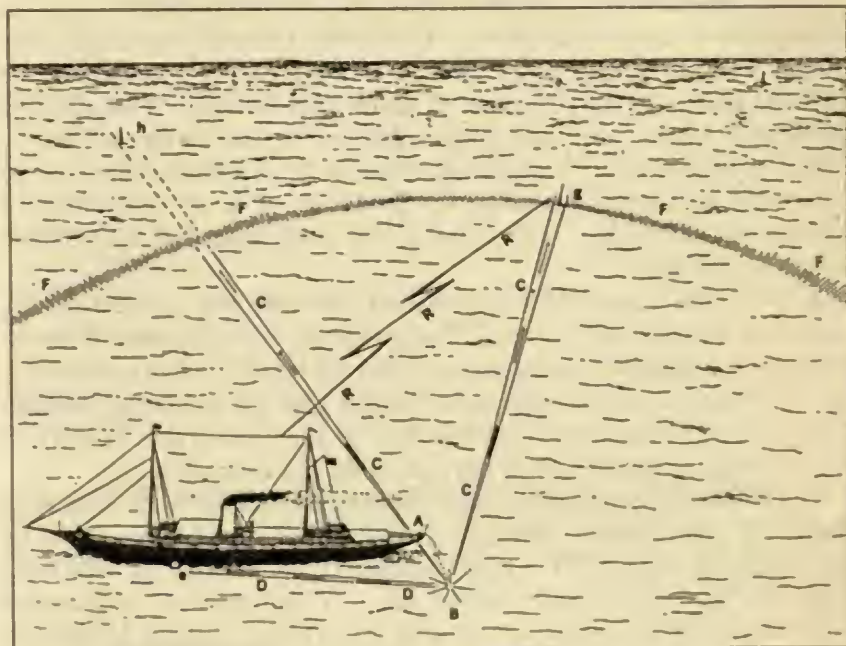


FIGURE 1.—Radio acoustic ranging. In hydrographic surveying the ship's position is determined by subaqueous sound travel to sono-radio buoys anchored at known positions. A, the bomber throws a small TNT bomb overboard from the moving ship. B, the bomb explodes and the resulting sound wave travels toward the sono-radio buoys (g and h) via paths (C—C) and toward the hydrophone (e) in the bottom of the ship via the path (D—D). The sound wave (F) travels in all directions at a velocity of about 1.5 km. per sec. Instantly on arrival at a sono-radio buoy (g) a radio signal (R) is transmitted which is received at the ship. In the figure the sound wave has not yet arrived at sono-radio buoy (h).

automatically by radio, and received and recorded on board the survey ship. From these data, the elapsed time between the origin of the sound and its receipt at each station is known and the position of the survey ship may be determined.

This is the method used by the Coast and Geodetic Survey, and is considered the most practicable for use in hydrographic surveying because all operations are controlled from the survey ship and all

data are recorded thereon and become available to the hydrographer in the shortest possible time. This method avoids errors made in transmission, which are always possible where the data are received elsewhere and radioed to the vessel.

R. A. R. OPERATION

To determine a position by R. A. R., the following data must be known: The receiving stations (that is, the hydrophones) must be established at known positions. The travel times of the subaqueous sound from its origin to its receipt at each receiving station must be measured with an accuracy of about 0.01 second. The effective horizontal velocity of sound must be known. (The travel path of the sound is not necessarily a straight line, as is explained later, but to determine horizontal distances by R. A. R., it is obvious that the velocity of sound that is required is the horizontal distance divided by the travel time.)

A sheet with a projection is prepared on which the positions of the receiving stations are plotted. The measured travel times are multiplied by the effective horizontal velocity of sound to obtain the horizontal distances between the sound source and the receiving stations. The position of the sound source is then at the intersection of the arcs drawn from the stations with the computed distances as radii.

The following description illustrates briefly how R. A. R. is used by the Coast and Geodetic Survey: A subaqueous sound is produced by the explosion of a TNT (trinitrotoluene) bomb thrown overboard from the survey ship while under way. A hydrophone (subaqueous receiving unit) in the hull of the ship, and a radio receiver on the ship are connected to a chronograph. The receiving station consists of a submerged hydrophone connected to a radio transmitter which operates automatically when the hydrophone is actuated by a subaqueous sound.

In addition to the ordinary survey personnel, certain specialists are required in R. A. R. One officer is in direct charge of all operations; he plots the ship's positions as determined from the R. A. R. data. A chronograph attendant is in charge of the chronograph and oversees its functioning during the time from the bomb explosion to the receipt of the radio signals. A radio technician is in charge of the instrumental equipment on the survey ship; he attends to the proper tuning of the radio receiver and assists the chronograph attendant in identifying the radio signals from the receiving stations. An explosives expert, called a bomber, is in charge of the explosives and the preparation of the bombs; he lights the bomb and throws it overboard when instructed to do so by the chronograph attendant.

One minute before an R. A. R. position is desired, an electric bell signals the bomber to get a bomb ready. The bell signal also indicates the size of bomb wanted. A detonator and fuse are inserted in the bomb and the fuse is lighted a few seconds before the time for the position. When the fuse is burning, the bomb is thrown overboard from the ship's quarter and a bell is rung as it strikes the water. This is the official time of the position. (The time of the explosion, which comes 7 or 8 seconds later, is not the time of the position, because by that time the ship is some little distance away from the place of the explosion.) The electric bell is heard by the officer in charge and by the chronograph attendant. The time and log are read and recorded and a sounding is taken. Any changes in course or speed are made at this time. At the sound of the bell, the chronograph attendant starts the chronograph and connects it with the ship's hydrophone. When the bomb explodes, the sound is received through the hydrophone and registers automatically on the chronograph tape. After the explosion has registered on the chronograph tape, the chronograph is switched from the hydrophone to the ship's radio receiver. The sound of the bomb explosion travels through the water in every direction and eventually reaches the several receiving stations. At the instant the sound arrives at each receiving station hydrophone, the radio transmitter connected to it automatically sends a radio signal, which is received on the ship's radio receiver and registers on the chronograph. During this time, which may be from a few seconds to more than 100 seconds, a mark is being made each second (or each tenth second) on the chronograph tape. As the radio returns are registered, the chronograph attendant identifies them, and when the last one has been received, the time intervals, in seconds and hundredths of seconds, from the explosion to its receipt at the several receiving stations are taken from the tape. Each radio return and its corresponding distance must be correctly identified with reference to the station from which it was received. The time intervals are then reported by the chronograph attendant to the officer in charge who determines from them the position of the survey ship at the time the bomb struck the water. This entire operation takes on the average about 4 or 5 minutes.

R. A. R. RECEIVING STATIONS

Three different types of receiving stations have been used by the Coast and Geodetic Survey. In their chronological development they are: Shore station, ship station, and sono-radio buoy. Ship stations are no longer used; shore stations are sometimes used; but sono-radio buoys are used in most R. A. R. surveys.

Shore stations.—R. A. R. was first used by the Coast and Geodetic Survey on the Pacific coast of the United States. Here comparatively

deep water generally extends reasonably close to the shore and, as is now known, the temperature conditions of the water are favorable for horizontal transmission of sound. Shore stations were used at this time. A shore station consists of a conventional radio receiving and transmitting station installed on shore, connected by electric cable with a submerged hydrophone placed offshore in an appropriate depth of water where it is not shielded by shoals. The hydrophone is attached to an anchor, but is buoyed to float at a selected depth below the water surface.

Each shore station is manned by one or more radio technicians. The principal advantage of shore stations is that the radio technician can keep the apparatus in repair, the batteries charged, and the station operating at maximum efficiency at all times. Surf or other uncontrollable conditions may actuate the hydrophone if it is too sensitive. The radio technician can vary the sensitivity of the apparatus for the best reception. He can also listen to the sound of the bomb explosion when it is received and can measure its amplitude. A knowledge of the strength of the received sound is valuable to the officer in charge in weighting the results and in determining the size of bombs to use.

Shore stations are more expensive to establish and maintain than sono-radio buoys, but their efficiency is greater. Laying the cable from the hydrophone through the surf to the radio station is the most difficult part of the establishment of a shore station, and sometimes weather may prevent it for several weeks at a time. And unless the area in the vicinity of the hydrophone has been thoroughly sounded, one has no assurance that intervening shoals or irregular types of bottom will not interfere with the receipt of the sound.

Ship stations.—When R. A. R. was first used on the Atlantic coast of the United States, it was soon found that shore stations would not function satisfactorily. The Continental Shelf on this coast generally extends many miles seaward, and the depths of water on it are comparatively shallow. Moreover, the temperature conditions of the water are not so favorable for the transmission of sound as they are on the Pacific coast. To overcome these difficulties, small ships were anchored offshore at known positions and used as floating R. A. R. stations. The receiving stations could then be placed in deeper water, thus shortening the distance through which the sound had to travel. The shore apparatus was placed on the ship, and the hydrophone was anchored, as at a shore station, a short distance from the ship so that ship noises would not interfere. These ship stations were then operated just as shore stations. They had all the important advantages of shore stations and in addition they were mobile. Their maintenance, however, was exceedingly costly, and as the ships were small, they frequently had to

leave their stations in bad weather or be exposed to damage by storm. Ship stations are no longer used by the Coast and Geodetic Survey.

Sono-radio buoys.—Soon after ship stations had been used successfully, the idea was conceived of using a buoy in which was housed a fully automatic unit for receiving the sound impulse and transmitting the radio signal—hence the name sono-radio buoy.

Two types of structures have been used for sono-radio buoys: One type in which a steel drum is held in a wooden framework, and the other a specially designed all-metal type. The latter requires more special fittings and parts than the former, but both are about equally successful. These buoys are constructed on the ship by the ship's personnel, using readily available materials.

From its long experience with the use of buoys as water signals, the Coast and Geodetic Survey has evolved a more or less standard type of wooden structure which has been used in the construction of sono-radio buoys. Such a buoy consists of a 50-gallon steel drum with a counterweight to hold it upright and a superstructure extending about 16 feet above the water, the batteries, the radio transmitter, and the necessary electric circuits being placed in the drum. A vertical antenna is supported on the superstructure and the hydrophone is suspended from the counterweight at a depth of about 7 fathoms.

The electric apparatus in the sono-radio buoy was designed especially for automatic use in R. A. R. The principal parts of the equipment are the audio amplifier, the keying circuit, the radio transmitter, and the hydrophone. All parts must be especially constructed and are generally made by the radio technicians on the survey ship. The apparatus used in all sono-radio buoys is very similar, although minor differences have been incorporated depending on the conditions encountered. Sono-radio buoys can be used from 1 to 3 months without attention.

The frequency of the sound of a bomb explosion is below 300 cycles. The electric apparatus is designed to receive and amplify sounds in this frequency range. The amplifier must be stable and any time lag in it must be small and relatively constant. The purpose of the keying circuit is to cause the radio transmitter to operate automatically when the bomb signal actuates the hydrophone. It is designed so that unwanted sounds of comparatively low intensity will not operate the radio transmitter, but that when the sound of a bomb is received the transmitter operates instantly at nearly full power.

Extra circuits are sometimes incorporated in sono-radio buoys for the purpose of shortening the transmitted radio signal. When radio returns are being received from several sono-radio buoys, it is obvious that an early return which is prolonged unduly may blanket subsequent returns coming immediately afterward from other sono-radio

buoys. Due to reverberation, multiple reflections, and other causes, a radio signal in such cases may be prolonged as much as 7 seconds. Moreover, defects occurring in the electric circuits or unwanted noises may tend to make a particular sono-radio buoy transmit almost constantly. The so-called shortening circuit limits the length of radio transmission to a half second or less, after which the sono-radio buoy is rendered inactive for a period of 3 to 5 seconds. There are certain disadvantages in using these circuits. When all the radio signals transmitted are of equal length, signals caused by bombs cannot be distinguished from other signals, as, for example, those caused by water noises. Moreover, if a sono-radio buoy is actuated by an extraneous cause just before the bomb signal arrives, the silencing circuit prevents the bomb signal from operating it. Shortening-and-silencing circuits, therefore, are not used where prolonged signals are not particularly bothersome.

To obtain constancy of radio frequency, a quartz crystal is incorporated in the transmitter. Several radio frequencies between 2492 and 4160 kilocycles are authorized for use in sono-radio buoys, but those most frequently used are 4135 and 4160 kilocycles. Using these latter frequencies, the minimum radio frequency power required for satisfactory results under normal operating conditions is about 3 watts, although up to 26 watts has been used.

A hydrophone is a subaqueous sound-detecting device. It is used in R. A. R. to receive the sound energy from a distant underwater bomb explosion and to convert it to electric energy. Most hydrophones consist of a watertight housing containing an electromagnetic, piezoelectric, or other electroacoustic device, which is coupled to the housing in such a way that the sound impinging on the housing, or on its diaphragm, is transmitted mechanically to the electroacoustic device, which in turn converts this mechanical energy into electric energy.

As sound passes through an elastic medium, such as water, there is an alternate condensation and rarefaction of the medium at a given point, resulting in a corresponding increase and decrease of the pressure at this point. In addition, at any point the particles of the medium undergo regional displacement forward and backward along the direction of sound propagation. Hydrophones are operated by this pressure variation and particle displacement. Several different types of hydrophones have been designed especially for use in R. A. R. The hydrophone itself does not have to be extremely sensitive, but the hydrophone and the audio amplifier must be designed so that together they will have the required sensitivity. A hydrophone must respond well to the frequency of a sound caused by a subaqueous explosion. The hydrophone must not be directive to a marked degree, for in hydrographic surveying the sound which is to actuate it may come from

almost any direction. The hydrophone or the case in which it is housed must be watertight. The most frequent cause of hydrophone failure is leakage. A hydrophone becomes inoperative if the armature of the electromagnetic unit is forced against one of the pole pieces and held there. This may result if a bomb explodes too close to the hydrophone or if anything strikes the hydrophone while the sono-radio buoy is being placed on its station.

Before a sono-radio buoy is put on station, the gain of its audio amplifier must be adjusted for sensitivity. If the gain is too low, the unit will be insensitive and returns will not be received from bomb explosions more than a short distance away. If the gain is too high, the unit will be actuated by the action of the waves, nearby water noises, or by the movement of the buoy itself. In the latter case, the buoy transmits continuously, and the receipt of a bomb explosion cannot be detected. Furthermore, the continuous radio signals interfere with the receipt of signals from other sono-radio buoys which are operating satisfactorily. It is obvious that a sono-radio buoy placed on station to operate automatically for several weeks at a time must not be adjusted for operation in perfect conditions, for then survey operations would often be interrupted by weather conditions. This explains one of the principal advantages of a shore station. The latter being attended, its sensitivity can be adjusted at all times for best operation.

Abnormal performance of a sono-radio buoy is usually disclosed in one of two ways—either it is too insensitive to bomb explosions or there is an excess of stray signals.

SHIP EQUIPMENT

The special equipment used on the survey ship for R. A. R. is comparatively simple and easily understood. It consists of a hydrophone in the ship's bottom, a radio receiver, a chronograph and amplifier, and a break-circuit chronometer. Except for the chronograph amplifier, standard commercial products are used in each case. Their coordinate functions from the time a bomb explodes until the radio signals from the R. A. R. stations have been recorded on the chronograph are as follows:

The bomb explosion is received on the hydrophone, after which the signal is amplified sufficiently to operate the stylus of a chronograph which makes a mark on a moving tape. The stylus circuit is then immediately connected to the radio receiver. Signals from the R. A. R. stations are received and marked on the tape by the same stylus. Another stylus operated from a break-circuit chronometer marks regular time intervals on the tape during this entire period. Then the time intervals from the explosion of the bomb to the reception of the radio signals may be measured on the tape.

The hydrophone, through which the sound of the bomb explosion is received, is installed in a water-filled tank which is fastened to the inner side of the hull of the ship. It must be located where ship noises will affect it least.

Any good commercial communication radio receiver may be used so long as it will cover the necessary range of frequencies.

The chronograph amplifier is especially built by the ship's radio technicians. Its purpose is to amplify the impulse from the hydro-

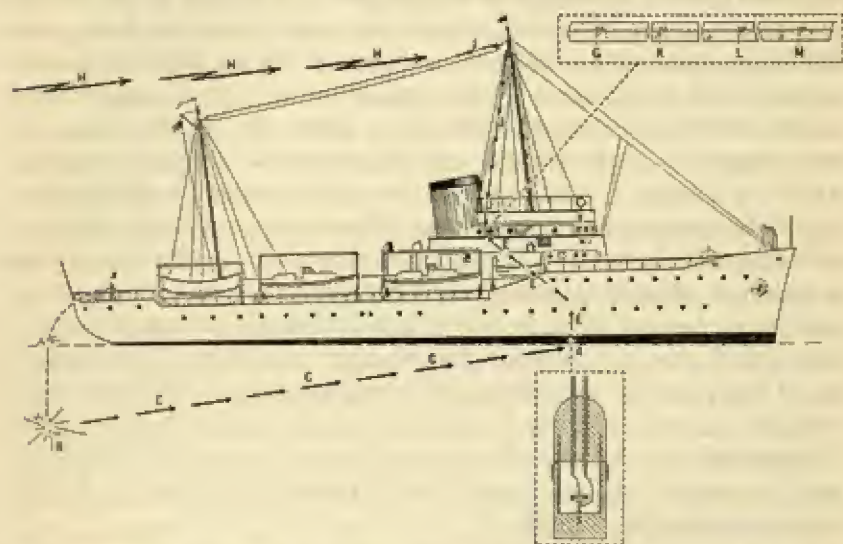


FIGURE 2.—Ship equipment for radio acoustic ranging. A bomber (a) throws a small TNT bomb overboard from the moving survey ship. The sound wave produced by the subaqueous explosion travels (CCC) to a hydrophone (d) in the bottom of the ship. The hydrophone converts sound energy to electric energy, which is led (EEE) to an amplifier which operates a chronograph (f). The bomb explosion is registered on a paper tape at G. The sound wave of the explosion travels to R. A. R. stations which it actuates and which instantly send radio signals (HHH) which are received (JJJ) and amplified and registered on the same chronograph (f). The returns from three stations are shown at K, L, and M. Knowing the velocity of sound in sea water, the time intervals on the tape can be converted into distances.

phone caused by the bomb explosion and also the output of the radio receiver. The amplification must be sufficient to actuate the stylus in the chronograph.

A chronograph is a graphic-recording time-measuring device. It is connected to a break-circuit chronometer, which provides the time record. A narrow wax-coated paper runs through the chronograph beneath two sharp styluses electromagnetically operated. The tape moves at the rate of about 2 centimeters a second. One stylus is con-

nected with the chronometer and makes a mark on the tape once a second. Another stylus is connected with the chronograph amplifier and is actuated by the reception of the bomb signal and later by the reception of the radio signals. This record permits the scaling of the time intervals to the nearest 0.01 second by interpolation.

A different instrument, called the Dorsey chronograph, designed and built by the Coast and Geodetic Survey, is also used for the same purpose. It incorporates electric time measurement, starting with a piezoelectric crystal, and provides much more constant and correct time than a break-circuit chronometer. The tape in this chronograph runs at a speed of about 5 centimeters a second, and a mark is made each tenth second and the seconds are numbered. The instrument is also automatic in that the electric bell signal signifying that the bomb has struck the water starts the tape moving and the timing stylus begins marking tenth seconds. When the hydrophone is actuated by the bomb explosion, the next tenth second is marked zero and the mark at each subsequent second is numbered. Time intervals to the nearest 0.01 second can be interpolated from this record by eye.

BOMBS

For use in R. A. R. a sound of great intensity reaching a peak almost instantly and one that will travel through the water in all directions is required. The explosion of a trinitrotoluene (TNT) bomb has been found best adapted for the purpose, although any type of explosive suitable for use under water can be used. Dynamite has been used, but it is more unstable and more dangerous to handle than TNT. The frequency of a bomb explosion is below 300 cycles, which is lower than most interfering noises.

The TNT itself does not have to be in a watertight container. For best results the container should be made of a comparatively strong rigid material so that the gases generated are contained until detonation is complete, whereupon the container bursts. The resulting explosion produces a highly compressed sound wave that has a greater range than one from an explosion in a comparatively fragile container.

For long distances and best results, hollow cast-iron spheres with half-inch walls, containing from 1 to 4 pounds of TNT, are used. These spheres have to be especially cast and are expensive and heavy to handle. For ordinary distances and for perhaps 95 percent of the cases, ordinary commercial tin cans with a friction top are used. Three sizes of the latter are commonly used, $\frac{1}{4}$, $\frac{1}{2}$, and 1 pint, depending on the distances involved and the characteristics of the area being surveyed.

Ordinary commercial detonators made of fulminate of mercury are used with standard waterproof fuse to detonate the TNT. Tin cans

of various sizes are filled in advance with TNT compacted firmly. A hole is punched in the center of the lid of each can. Fuses of various lengths are attached to the detonators and this junction of the fuse and detonator must be watertight. Just before an R. A. R. position is required, the detonator is inserted through the hole in the lid of the can and pushed down into the TNT. The fuse is lighted on an electric heating element and the bomb is thrown overboard well clear of the ship, which is under way.

The bombs must not be exploded too close to the survey ship. Also they should not explode too close to the surface of the water, for then part of the sound energy is dissipated into the air. Best results are apparently obtained with explosions at a depth of about 7 fathoms. To achieve these two results, the bombs are weighted to make them sink at the required speed, and the fuse is cut in lengths to provide the required delay in time.

In 1940 the cost of a 1-pint bomb with fuse and detonator was about 30 cents.

VELOCITY OF SOUND IN SEA WATER

To measure distances by subaqueous sound transmission, one needs to know not only the elapsed time intervals but the *effective horizontal* velocity at which the sound travels through the water. The velocity of *propagation* of sound in sea water may be calculated from the temperature and salinity of the water and the hydrostatic pressure. Tables have been prepared based on these three variables. The velocity of sound varies with these three characteristics by the following approximate percentages:

(a) Each 1° C. increase in temperature increases the velocity 0.2 percent.

(b) Each 1 part per 1,000 increase in salinity increases the velocity 0.1 percent.

(c) Each additional 100 fathoms (183 m.) of depth increases the velocity 0.22 percent. The velocity of sound in water is approximately 1,500 meters per second at a temperature of 14° C., salinity 35 parts per 1,000, and at surface atmospheric pressure.

To determine the velocity of sound from the tables, the temperature and salinity of the water must be measured, and the depth must be known, for pressure varies almost exactly with depth. The variation of salinity in sea water is small, and its effect on velocity, as compared with the effect of variation in temperature, is relatively unimportant. The temperature varies not only from place to place, but ordinarily decreases with the depth. For the average R. A. R. survey, the velocity of sound must be known within 4 meters per second, and to attain this

accuracy the average temperature of the water through which the sound wave passes must be known within approximately 1° C.

During a hydrographic survey controlled by R. A. R., frequent temperature observations are made. Observations from the surface to the bottom are made at various places and times, supplemented by more frequent observations at the surface and the bottom. Temperatures are measured with one or more reversing thermometers attached to a sounding wire and lowered to the desired depth. The thermometer reverses as soon as it starts upward and breaks the column of mercury so that the value registered at the greatest depth can be read after the thermometer has been brought to the surface.

A bathythermograph, a comparatively new instrument, is also used to measure water temperatures in the upper 75 fathoms, where the greatest variation occurs. This instrument records automatically and graphically the temperatures with reference to depths.

The variation in salinity normally encountered affects velocities of sound only slightly as compared with temperature, but salinity does vary and its value must be determined. In the Coast and Geodetic Survey the salinity is determined indirectly by measuring with a hydrometer the specific gravity of a water sample. An accuracy of about one-tenth part per 1,000 may thus be obtained.

Velocity of sound as determined from the physical characteristics of the water and from tables is obviously the velocity of propagation of the sound wave, irrespective of direction. The effective horizontal velocity is required in R. A. R. If the sound wave is refracted, or is reflected from the bottom one or more times en route to the receiving station, as is explained later, it is apparent that the theoretical velocity alone will not suffice for use in R. A. R. In such cases, the measured time intervals are greater than they would be if the sound traveled by a direct horizontal path.

Under certain conditions the effective horizontal velocity of sound at a place can be determined experimentally. If a bomb is exploded at a known horizontal distance from a receiving station and the time interval from the explosion to its receipt at the receiving station is measured, the distance divided by the time interval will give the effective horizontal velocity of sound between the source and the receiver for the temperature and salinity of the water at that place and time, irrespective of the path of the sound wave. Where the depths of water permit, it is customary to make such tests throughout an area being surveyed and at intervals during the survey. For a survey in uniform depths where the temperature and salinity are relatively constant, results of such tests can be subsequently used in determining R. A. R. positions. Where the temperature and salinity change frequently, the velocity of sound determined by tests can be modified to take into

account the temperature and salinity differences. But where the depths in the area vary to a marked degree, and especially where the depths are too great to permit tests to be made, the velocity of sound values must be determined from an assumption of the path of the sound wave.

There is also an indirect method for determining the effective horizontal velocity of sound under certain conditions and allowing certain assumptions. If the time intervals from a bomb explosion to three receiving stations at known positions are measured accurately, and the same temperature and salinity conditions and depths along the three paths of sound are assumed, then the effective horizontal velocity can be computed by means of a rather involved formula. It is obvious that there must be no doubt regarding the accuracy of the travel times. If one value is doubtful or if the conditions along the three paths are dissimilar, an erroneous value of the velocity of sound will result.

PATH OF A SOUND WAVE

In an ideal water medium with uniform characteristics and unlimited dimensions in every direction, a sound from a nondirectional source would be propagated along straight paths in every direction. The arrival time at any receiving station would be the time required for the sound to travel the shortest path. In such a case, the theoretical velocity of sound would be the same as the effective velocity, and R. A. R. would not be complicated by uncertainties due to the path of the sound wave.

Unfortunately, the ideal medium does not exist in practice, and the propagation of sound in water is indeed complicated. The sound wave is propagated through a body of water bounded above by the water surface and below by the ocean bottom; the horizontal dimension of the medium is long as compared with its vertical dimension; sound waves are reflected from both boundaries of the medium, and within the medium they are refracted by changes in the velocity of sound along the path. These facts complicate the path of the sound wave.

The reception of sound is also complicated by the fact that the various reflected and refracted waves interfere with one another. Where two sound waves of the same frequency and wave form meet at one point, they will tend to reinforce or neutralize each other, depending on their directions of propagation and whether they meet in the same or opposite phases.

It is apparent that, in a bounded water medium, the sound wave may travel an almost unlimited number of paths. There will be one direct path from the source to the receiver and a multitude of reflected paths. The sound wave that first arrives at the receiver with sufficient

intensity to actuate it is, of course, the one that is used in R. A. R.—other sound waves arriving later serve only to prolong the received signal. Unfortunately, the sound traveling via the direct path is almost always canceled by the sound wave reflected from the surface of the water. This surface-reflected sound wave is reversed in phase, and as the length of its path is nearly equal to the direct path, almost complete cancelation of the two takes place. In actual experience the sound via the direct path is rarely received at distances greater than 7 or 8 miles.

The result of this is that the useful sound wave in R. A. R. is the one that is reflected at least once from the ocean bottom and, depending on the depth of the water and its physical characteristics, the sound may arrive at the receiving station after having been reflected a number of times between surface and bottom.

Another complication is the fact that the surface boundary is horizontal, but the ocean bottom is not. A sound wave is reflected from a boundary in the same way as a ray of light is reflected from a mirror, the angle of reflection being always equal to the angle of incidence. If the water is deep at the bomb explosion but the receiving station is located in comparatively shallow water, as is the usual case in R. A. R., it is obvious that the bottom slopes upward along the effective path of propagation. In such a case, each time the sound wave is reflected from the bottom, its direction of propagation is changed toward the vertical, and if enough reflections are involved and the slope of the bottom is sufficiently great, the successive angles of reflection may be decreased until the sound wave is reflected vertically upward or it may actually reverse its horizontal direction of propagation, and never reach the receiving station. This condition is aggravated in shoal water where more reflections take place in a given horizontal distance than do in deep water of the same characteristics. This partly explains the difficulty encountered in sound transmission from deep water on the Continental Slope to shoal water on the Continental Shelf. It also explains the difficulty encountered in R. A. R. where there are intervening shoal areas between the bomb explosions and the receiving stations.

The path of a sound wave is also affected by refraction. Wherever a change in the velocity of sound takes place along the path, the sound wave is refracted. If pressure were the only characteristic affecting velocity of sound, its constant increase with depth would cause a constant increase in velocity, and the sound wave would be refracted in the arc of a circle concave upward. It is rare, however, that pressure is the only variable involved. The temperature of the water varies and normally decreases with depth more than enough to overcome the increase caused by pressure, until the depths become comparatively

great. This decrease in temperature causes a decrease in velocity which refracts the sound wave downward.

Thus it is seen that for any given case in R. A. R. the path along which the received sound has traveled may be very complicated. It may have been reflected a number of times from the bottom and the surface, and between these reflections it may have been refracted, either upward or downward, or perhaps in both directions at different depths.

The excellent results obtained in R. A. R. are due to the fact that water is a relatively good medium for the propagation of sound, even though its physical characteristics, and consequently the velocity of sound, vary with time, place, and depth. It is due also to the good reflecting qualities of the water surface and the ocean bottom. The sound is confined vertically and is reflected and amplified, somewhat as it is in a speaking tube. Little of the energy of the sound wave is actually lost in reflections, although when the sea is rough or the ocean bottom irregular, some of the sound energy may be dissipated.

R. A. R. IN PRACTICE

Subaqueous sounds have been detected with instruments of only ordinary sensitivity at a distance of 400 nautical miles (740 km.). A sound propagated vertically downward by an electromagnetic oscillator in a depth of about 200 fathoms (365 m.) has been heard after having been reflected 23 times alternately from the bottom and the surface. In R. A. R. the longest distance that has been measured is 184 nautical miles (340 km.). This was in connection with a test which was concluded at that distance, but there was no observable diminution in the intensity of the received sound as compared with that received at somewhat lesser distances. In actual hydrographic surveying, distances of 100 miles (185 km.) or more have often been measured. Shore stations are much more efficient in this respect than sono-radio buoys, although returns have been received from sono-radio buoys at distances of 100 miles (185 km.). The type of area in which sono-radio buoys are preferred to shore stations ordinarily limits their range to about 30 or 35 miles (55 or 65 km.).

The operation of R. A. R. to control hydrographic surveys is now a routine procedure. The position of the survey ship is fixed regularly by R. A. R. at intervals of 10 minutes or less with as much casualness as if three-point sextant fixes were being used.

The positions of the receiving stations are plotted on a projection, just as the positions of triangulation stations are. Because of the long distances ordinarily involved, the distortion which occurs in a plotting sheet made of even the best drawing paper has considerable effect. For this reason, a number of uniformly spaced concentric circles are

drawn on the sheet from each R. A. R. station at the time the projection is made.

The position of the survey ship can be plotted with a beam compass, by swinging distance or time arcs from the respective receiving stations, but setting the beam compass with reference to the nearest of

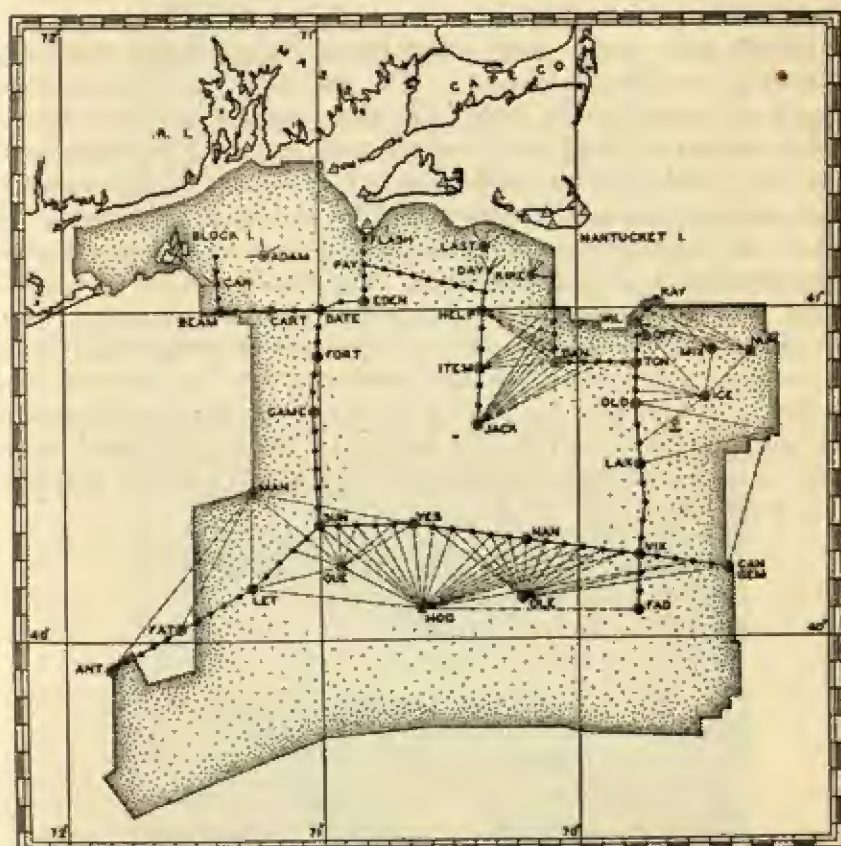


FIGURE 3.—An area surveyed in 1939 by radio acoustic ranging (R. A. R.), showing the sono-radio buoys and ordinary buoys used to control the hydrography. The lines of buoys were located by taut-wire traverses, but some of the outermost sono-radio buoys were located by R. A. R. distances. Legend: ● ordinary survey buoy; ○ sono-radio buoy; △ triangulation station; ← sextant fix; — taut-wire measurement; — . — . R. A. R. distance.

the concentric circles. The position of the ship is at the intersection of the arcs. Positions can also be plotted by using a special circular celluloid protractor.

R. A. R. was originally adopted to control hydrographic surveys beyond the visibility of shore signals or where survey buoys could not be used. Since its use, however, does not depend on visual observation,

it is equally usable at night, or in fog. Survey ships of the Coast and Geodetic Survey, using R. A. R., have surveyed continuously 24 hours a day for periods of 10 days at a time.

Some statistics of a survey controlled exclusively by R. A. R. may be of interest. They are from an offshore survey in the vicinity of Nantucket Shoals off the northeast Atlantic coast of the United States. These surveys were plotted on one 1:60,000 scale sheet and two 1:120,000 scale sheets. Sono-radio buoys were used for receiving stations at 24 different locations. The surveying was done between May 2 and September 25, 1939. The area surveyed was 8,562 square statute miles (22,176 sq. km.), and the total length of sounding lines was 10,496 statute miles (16,892 km.); 5,506 bombs of various sizes were used, made from 3,511 pounds of TNT and 4,170 feet of fuse. To obtain the required temperature and salinity data, serial temperatures were observed at 135 different places. The positions of the sono-radio buoys were determined by taut-wire traverses, in connection with which ordinary buoys were used at 60 different locations, in addition to the sono-radio buoys. The total number of working days was 101, including 18 days used for placing or picking up buoys and running the taut-wire traverses for their locations. The survey vessel ran a total distance of 16,481 nautical miles (30,543 km.) for all purposes during the survey.



SONO-RADIO BUOY (ALL-METAL TYPE).

THE DAVID W. TAYLOR MODEL BASIN¹

BY REAR ADMIRAL HERBERT S. HOWARD, U. S. N.

Director, David W. Taylor Model Basin

[With 4 plates]

The largest and most completely equipped ship-model testing and experimental plant in the world operates directly under the Bureau of Ships of the Navy Department.

This plant, the David W. Taylor Model Basin, staffed by a highly trained and capable group of officers and civilian technical and shop personnel, has as its basic function the solving of problems concerning the design and operation of naval vessels by testing models in water under controlled conditions. Included in its work are the determination of the speed and powering of ships, launching, stability, action in waves, turning and maneuvering, and propeller design. Besides questions of pure ship design and form, the problems presented for solution cover the field of mine-sweeping devices, paravanes, and torpedoes; in fact, everything which has to do with forms which move through the water.

In addition to the preceding problems, special problems of structural design of ships comprise a major activity of the plant. These problems cover all manner of special questions relating to the strength of ships and their parts, the resistance of ship structures to underwater explosions, structural vibration, and the effect of shock, and the elimination of such vibration and shock effects.

In general, the chief function of this organization at present is to give the earliest possible solutions or answers to the wartime problems submitted to it. Research, which has been and is being continuously carried on, gives the background of knowledge which makes it possible to undertake and furnish the solution to these urgent problems.

Although the Model Basin operates directly under the Bureau of Ships, work is carried on not only for that Bureau but for all branches of the Navy Department, whether for the Commander in Chief himself or any of the technical bureaus. Work is also done for other branches of the Government, notably the United States Maritime

¹ Reprinted by permission from *Journal of Applied Physics*, vol. 15, No. 3, March 1944.

Commission, and for private companies and individuals, this practice fulfilling the requirements of the act which created the establishment.

The construction of the Taylor Model Basin was authorized by Act of Congress of May 6, 1936. This act gave authority for the purchase of a suitable site and the construction of a new model basin establishment for the United States Navy. This was to replace and extend the work of the original Experimental Model Basin which had been in service at the Washington Navy Yard for nearly 40 years. The old experimental basin had become too small to carry out its work for the Navy and private individuals, and its equipment was, moreover, becoming obsolete.

To commemorate the work of that officer who had been responsible for the original Experimental Model Basin and under whom that basin had operated for the greater part of its existence, the Secretary of the Navy directed that the new establishment be known as "The David W. Taylor Model Basin" in honor of Rear Admiral David Watson Taylor, Construction Corps, United States Navy, Retired, former Chief Constructor of the Navy.

The location chosen for the new establishment was in the valley of the Potomac some 12 miles from the center of Washington. This site was selected not only because land was available but principally because three basic requirements were fulfilled. First, solid rock was at the surface in this location; this meant that the foundations for the rails of the towing carriages of the basins could be carried down to solid rock and the extremely accurate alignment needed could be practically guaranteed. Second, an ample supply of clean fresh water necessary for the testing basins was available, since the main conduits to Washington were close at hand. Finally, the location was away from heavy traffic which might disturb the alignment of the towing-carriage rails and their foundations, but it was still fairly close to the Navy Department which permitted easy communication and frequent visits.

The new establishment was planned and laid out by Capt. H. E. Saunders, who had been stationed at the old Experimental Model Basin for a number of years. Based on long experience there and reports from model basins the world over, the new model basin was planned to provide not only the best and most up-to-date facilities and equipment for model testing, but in such size and capacity as to ensure, as far as could be foreseen, that it would meet all needs of the Navy for many years to come.

The actual design was undertaken in 1933-34 by the Bureau of Yards and Docks of the Navy Department and construction was started in September 1937. The basins were filled with water in March 1939 and the plant was completed in July of that year. Because of the

long time required for laying the carriage tracks and for making other preparations, the principal activities were not transferred from the Navy Yard until November 1940.

The original conception of this establishment, as indicated by the authorizing act, was that it should be constructed to investigate and determine the most suitable and desirable shapes and forms for naval vessels and to investigate other problems of ship design. Thus primarily the establishment was designed and equipped to carry out experimental work on the forms of ships' hulls and to estimate the power required to drive them, with a secondary interest in other features of design. This original conception has almost been lost sight of in an expansion and growth far beyond the fields originally contemplated. The war has naturally been principally responsible for this great expansion. Under the heading of "underwater forms and propulsion" the work has expanded until it has come to cover the proper form or shape of almost any body which is propelled, towed, or projected on or through the water; while under the secondary heading of "other problems of ship design" the expansion has been so broad in the fields of structural strength, shock, vibration, underwater explosions and related subjects that the primary and secondary objects of the original establishment have almost changed places.

The outstanding features of the Taylor Model Basin are its test facilities, which are unusual both as to types and as to size and capacity. For an understanding of the work undertaken a general description of the physical plant and these facilities is necessary.

As a testing establishment the Taylor Model Basin was made large enough to house equipment which would accomplish each of the various types of research on models with the greatest degree of accuracy and reliability.

Physically the establishment consists of three buildings: a main building 871 feet by 54 feet; lying parallel to it, a basin building 1,330 feet long; and a wind-tunnel building. The main building houses in its central section the offices, drafting and computing rooms, record storage vaults, a library, a photographic laboratory, and a museum.

The western section of the building contains the shops where wood and metal models, mechanical devices, instruments, dynamometers, and other special equipment are made.

The eastern end of the main building constitutes the laboratory. In this laboratory are located the 12-inch and 24-inch variable-pressure water tunnels, 30,000-pound and 600,000-pound universal static-load testing machines, and a 150,000-pound alternating-load testing machine, and other equipment.

The basin building is unique in its appearance, because of its barrel-arch roof 1,188 feet long. Instead of a single large model basin like

the old one at the Washington Navy Yard, there are four separate model basins each designed for a particular line of work.

The principal large deep-water basin is 963 feet long by 51 feet wide by 22 feet deep. Here models of large ships are towed or self-propelled. This is the largest basin of its kind in the world.

Joining the large basin is a shorter shallow-water basin 303 feet long by 51 feet wide by 10 feet deep. The depth can be varied at will to represent rivers, canals, and channels of limited depth and width. In this basin models of tugboats, barges, river craft, and other types of shallow-water vessels are tested.

Forming a continuation of the west end of the shallow-water basin is a J-shaped turning basin, for testing the maneuvering and steering characteristics of models. In a special enclosure over this basin, accurate photographic observations of the models under test are made with a group of cameras about 40 feet overhead.

To the north side of the large basin there is a high-speed basin 1,168 feet long by 21 feet wide by 10 feet deep, for the testing of models of high-speed motor boats and seaplane hulls. Incidentally, the site is large enough to permit the extension of this basin to more than twice its present length to meet requirements of the future.

In the basement of the main building is a small basin, 142 feet long by 10 feet wide by $5\frac{1}{2}$ feet deep, for the testing of special models and for unusual research problems.

The towing carriages, which span the basins and operate on the precision-laid rails atop the basin walls, furnish the means of testing the models. The heart of a towing carriage is the dynamometer, which with its related recording instruments measures the forces arising from the motion of a model through the water.

Two carriages are now in operation—carriage 1 over the deep-water basin, and a special quiet-running carriage with wood frame and pneumatic-tire wheels over the high-speed basin. Under construction, and to be placed in service during 1944, are carriages for the shallow-water basin and the high-speed basin. The last carriage will have a top speed of 24 knots.

The carriage which now operates on the deep-water basin is typical. The specifications it must fill are exacting: a testing speed range of from 0.1 to 18 knots, the selected speed to be constant during an 8-second measuring run within 0.01 knot, a rigid-frame structure to span the 51-foot distance between the basin walls without permitting disturbing vibrations or deflections at the midspan where the measuring instruments are located, absolutely straight-line motion of the towing point where the model is attached to the carriage, a dynamometer to measure the model resistance during the measuring run to within

0.01 pound but rugged enough to handle the forces on large, 30-foot battleship models at full test speed.

Two variable-pressure water tunnels, designed primarily for testing model propellers but also used extensively for special hydrodynamic tests, are among the unusual facilities. Each water tunnel consists of a closed duct circuit arranged in a vertical plane, in which water is circulated at a known speed. In the lower limb of the apparatus is a motor-driven impeller which circulates the water, and in the upper limb is the test section, fitted with glass ports for visual and photographic observation of the propeller being tested in a jet of water of uniform velocity and turbulence. The diameter of the jet nozzle is 12 inches for one of the water tunnels, and 24 inches for the other.

The model propeller is mounted on a motor-driven shaft projecting into the test chamber. The thrust and torque of the propeller at various speeds of revolution are measured by a dynamometer. Water speeds in the 24-inch tunnel up to 35 knots are available.

Vacuum pumps lower the air pressure above the water in the test chamber of the tunnel, in order to create an absolute pressure on the model propeller corresponding to the combined effect of atmospheric and water pressure on the propeller of the full-sized ship. Under these conditions, the phenomena of cavitation occur on the model propeller so that the test accurately represents the behavior of the full-scale propeller. Cavitation is the formation of water-vapor cavities, or "bubbles," on the propeller blade surface, caused by high loading and consequent serious reduction of pressure on the back, or "suction side" of the propeller. Efficiency suffers when cavitation occurs. Cavitation effects are studied by means of stroboscopic illumination of the propeller being tested, and these effects are recorded by high-speed flash photographs, of 1/30,000-second exposure.

In the laboratory building there are located two large machines for testing structural specimens, both full-size and model scale. One, the 150,000-pound alternating-load testing machine, tests beams, columns, riveted and welded joints, and other structural members in alternate compression and tension over long periods of time, to discover the manner, loading, and number of cycles to failure in fatigue.

The other large testing machine is a universal static-load testing machine with 600,000-pound capacity in either tension or compression. Stress-strain data, yield point, and ultimate strength of a wide variety of structural specimens may be obtained with this apparatus.

One of the most unusual and recently completed facilities is the test pond for underwater explosion tests. This is a pentagonal pond, dug partly out of the solid rock and partly formed by built-up rock embankments. It is roughly 150 feet across and will carry water to a

depth of 25 feet. In this pond research investigations of underwater explosions and explosive tests against models of ship structures are carried out.

Information can be obtained on the trajectories of model bombs and torpedoes after impact with the water surface by experiments made in the new transparent-wall tank, using high-speed motion pictures to record the paths of the models. The new tank has glass windows forming one side and one end; it is 25 feet long, 9 feet deep, and $4\frac{1}{2}$ feet wide, filled with continuously filtered, crystal-clear water to insure clear photographs. The windows are three-quarters of an inch thick "tempered" glass, four times as strong as ordinary plate glass of the same thickness. Intense photographic illumination is necessary to obtain good film records of the objects moving through the water.

The circulating-water channel, now nearing completion, is an unusual hydraulic testing facility, both as to type and size. Essentially it consists of an open-top test section 22 feet wide and 60 feet long in which a stream of water 9 feet deep flows at a maximum speed of 10 knots. The object under test will be held stationary in the moving stream and the forces exerted by the water measured by suitable dynamometers. The walls and bottom of this channel contain windows approximately 4 feet by $11\frac{1}{2}$ feet through which both visual and photographic observations can be made.

The chief advantages obtained by testing in the circulating-water channel are that the object undergoing test can be viewed and photographed from all sides and that the tests may be carried on for an indefinite period without stopping as at the end of a straight towing run.

The objects tested in this channel will consist of ship models, torpedo shapes, mines, and special devices which cannot be tested as well by towing in still water. The water channel will complement the existing turning basins and water tunnels but will not supplant them.

In order that such a large stream of water may be circulated at constant speed with uniform flow throughout the test section, a structure about 150 feet long and 45 feet high is required. The water is pumped through the channel by two $12\frac{1}{2}$ -foot-diameter propeller-type pumps driven by direct-connected 1,250-horsepower electric motors. These motors rotate at constant speed and the rate of flow of the water is regulated by adjusting the pitch of the propeller blades while running.

The wind-tunnel building is located to the west of the main building. It contains two steel wind tunnels, each with a closed rectangular test section 8 feet by 10 feet, and with single return passage. These tunnels are equipped with 4-bladed, 16-foot-diameter wooden propellers, one driven by a 1,000-horsepower motor, the other by a 700-horsepower motor. These motors are controlled by the Clymer system which per-

mits speed control within plus or minus $\frac{1}{2}$ percent. Air velocities can be varied from approximately 10 to 220 miles per hour. Six precision scales automatically record the three moments and three forces on the model. A seventh scale records the wind velocity.

Airplane models up to 8-foot wing span can be tested both for normal performance characteristics and for stability in yaw; two separate systems for supporting the model are used for these two types of test.

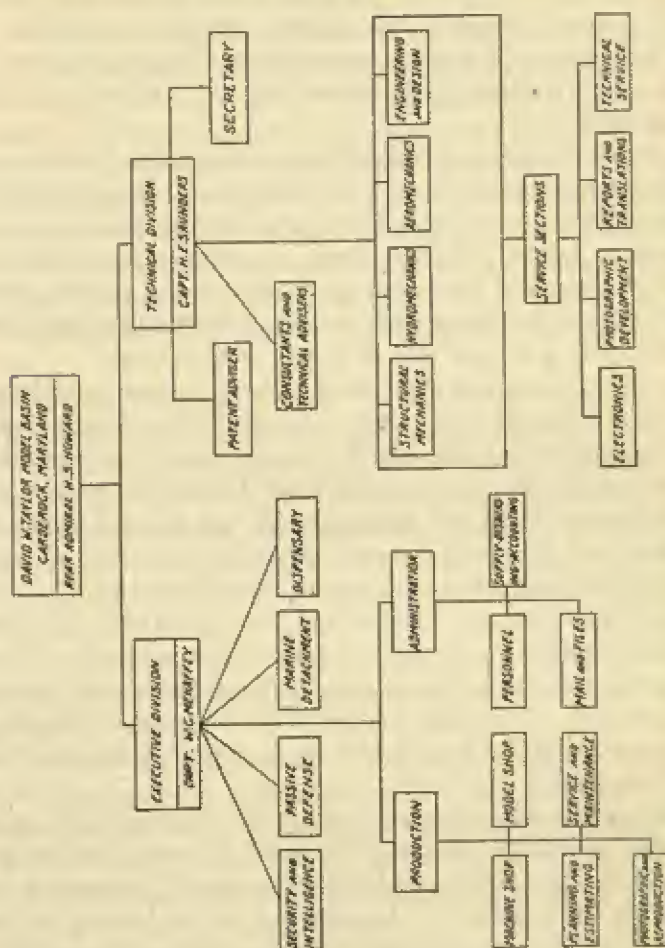


FIGURE 1.—Chart showing the organization of the David W. Taylor Model Basin.

At the present time tests for the Bureau of Aeronautics are still carried on principally in the old wind tunnels at the Washington Navy Yard, but within a short time the new tunnels will be actively operating.

The organization of the Taylor Model Basin is shown on the chart. Rear Admiral Herbert S. Howard, U. S. N., is director; Capt. Harold E. Saunders, U. S. N., who laid out the establishment and was in

charge of the entire work of preparing the facilities for operation, is technical director and head of the technical division; and Capt. W. C. Mehaffey, U. S. N. R., is executive officer and production officer.

The heart of the organization and the reason for its existence rest in the technical division. This division is divided further into three main divisions: hydromechanics, structural mechanics, and aeromechanics.

Each of these divisions is headed by a senior officer, with officer assistants, specially trained and qualified for this particular work. The civil technical staff is of the same high caliber, the nucleus of this staff possessing a national and international reputation in this highly specialized work.

In the hydromechanics division the principal work falls within the field of ships' lines, propellers, and underwater forms such as mine-sweeping gear and torpedoes. After the technical design of a device is completed, a model is built to scale, in order to carry out the test necessary to check the form and to determine the power needed to propel or tow it; the test is made in one of the various model basins. The procedure in a typical test of a ship is as follows.

The usual ship model is about 20 feet long, hollow, and fashioned from layers of wood glued together. It is carefully shaped to represent the outer surface of the ship's hull, to exact scale, from keel to deck. The model is complete as to its underwater form, with rudder, propellers, shafts, struts, bilge and docking keels, but without upper works.

The model is first towed, non-self-propelled, over one of the main basins by the carriage which has already been described.

In making a towing run the carriage starts from rest, and smoothly and gradually acquires the speed necessary for the test. When the carriage is towing the model at a uniform rate at the desired speed, and the model is producing its characteristic wave formation, the actual resistance of the ship model in pounds and hundredths of a pound is measured.

Later a second, self-propelled test is run, in which the model is driven under its own power along the basin with small model propellers. Small electric motors installed in the model, one motor to each shaft, operate the propellers. An operator on the towing carriage to which the model is attached regulates the speed of the model ship. From the tests so made, calculations give the corresponding results for the full-sized vessel.

Under the hydromechanics division is also carried out the design of propellers in connection with the Bureau of Ships, and the testing of model propellers based upon these designs. These model tests are made in one of the two propeller tunnels already described.

This division also carries out full-scale special tests aboard ships of the fleet, usually at the time of their trials, such as turning trials to determine the track of a ship under different conditions of speed and rudder.

The structural mechanics division is concerned with all questions of the strength of ships' structure, vibration, and related subjects.

The work in structural mechanics at the model basin had its inception a number of years ago in the thought that if the performance of full-sized ships could be accurately forecast through experimental work with models in a model basin, it should equally well be possible to forecast the performance of the structure of ships by the use of accurately constructed models, with proper technique in carrying out the tests. This would permit gaining knowledge as to the performance of such structures long before a ship itself was finished.

This work was started with elementary models of the hulls of ships, and sectional models of the hulls of submarines. Proving successful, it has been continued to the present time, until it now includes deck and bottom structures, turrets and their foundations, and similar projects.

The next problem undertaken in this field was the resistance of the structure of ships to underwater explosions. It was soon found that, for this work to be effective, fundamental knowledge must be gained as to the nature of the underwater explosions themselves. With the construction of the new Taylor Model Basin an extensive research program was taken in hand to investigate the effect of the explosion of small charges against simple diaphragms, and also to study the explosions of charges themselves, by the use of extremely high-speed underwater motion photography. From this research, information is being gained as to the nature of explosions themselves, and their effect upon the structure of ships.

A third most important work of this division is that of investigating vibration of ships' hulls and structural foundations, including support of instruments and other equipment aboard ship. Some of this work is done at the model basin but a large part of it is carried out aboard newly commissioned ships of the fleet when undergoing their first high-speed runs and gun-firing trials.

The work of the aeromechanics division, including the operation of the two new wind tunnels, is concerned principally with wind-tunnel tests of models of new designs of airplanes for the Bureau of Aeronautics of the Navy Department, and with tests to determine the effects of modifications to improve the performance of existing designs. Wind-tunnel tests are also made for the Bureau of Ordnance, and

other government departments, to assist them in special problems requiring aerodynamic information.

To construct the various types of models which are used in the investigations which have been described, two separate shops, one wood-working, the other metalworking, form an integral part of the establishment. The former exists particularly to manufacture the wood models of ships, aircraft, or other forms which are tested, while the latter constructs all special equipment, instruments, and other gear as well as any metal models used in the tests in the establishment.

In its highly technical work which, in many of its aspects, involves the measurement of infinitely small units of time, stress, and motion, the Taylor Model Basin has taken a leading place in the development of special instruments. As two examples in the field of instrumentation in which the organization has become preeminent, the work in ultra-high-speed motion pictures and electronics should be mentioned. The basin has taken a leading position in the development of high-speed motion-picture equipment and technique to record the details of lightning-fast phenomena such as shock and explosion, and also in the development of electronic measuring instruments accurately to record super-high-speed events such as the pressure curve of an explosion, or to measure infinitesimally small changes in displacement for obtaining data on vibrations and strains in structures.

From the preceding paragraphs it can be seen how large a part the work at the Taylor Model Basin plays in the technical side of the war effort. Every new design of ship, from aircraft carrier to landing barge, is checked and tested as to its form and power; minesweeping gear, insofar as its performance in water is concerned, is tested and run in model or full size; special weapons and devices which operate in or on the water are designed as to their hydrodynamic features; and the vibration of new ships and their ability to withstand shock are investigated. The list could be multiplied indefinitely.

This general description of the work undertaken and now under way at the Taylor Model Basin, and the special items listed, would not be complete without comment upon the quality of the technical reports which make available for use the actual results from these tests and projects. No matter how thorough and complete the technical studies and tests themselves may be, if they are not so written up and presented as to be understandable and clear for the use of the officials for whom the tests and studies are made, they might as well not have been made at all. Particular effort has been made in the preparation of better and clearer reports by progressive development of reproduction methods, lay-out styles, and writing technique, so that these reports may be readily understandable by those who desire to use them. The success of these efforts has been made evident in the widespread demand for

Taylor Model Basin reports throughout this country and abroad as well as by the various agencies of the Navy itself.

At present every effort of the Taylor Model Basin staff and its facilities is being applied to the one end which is to contribute to the maximum of their abilities to the early winning of the war. Pure research must take a secondary place, but it is only through the pure research carried on in peacetime and the skill so developed in the solving of similar problems that quick and correct answers can be found now for the urgent problems of the war.

The interest of the country in research has increased greatly in these most recent years. It is greatly to be hoped that when peace comes again this interest will not lag but will continue so strongly that this establishment may continue to operate at its full capacity, so that through the more extensive pure research then possible, technical improvements in the design and construction of our ships and naval weapons may increase. Thus, should war ever again be forced upon us, we may feel that we have kept ourselves prepared to meet the technical problems of that day.

The first of these is the fact that the United States is a young nation, and its history is therefore a history of growth and development. The second is the fact that the United States is a large nation, and its history is therefore a history of expansion and conquest. The third is the fact that the United States is a diverse nation, and its history is therefore a history of conflict and compromise. The fourth is the fact that the United States is a nation of immigrants, and its history is therefore a history of assimilation and integration. The fifth is the fact that the United States is a nation of pioneers, and its history is therefore a history of exploration and discovery. The sixth is the fact that the United States is a nation of farmers, and its history is therefore a history of agriculture and industry. The seventh is the fact that the United States is a nation of merchants, and its history is therefore a history of commerce and trade. The eighth is the fact that the United States is a nation of soldiers, and its history is therefore a history of war and peace. The ninth is the fact that the United States is a nation of statesmen, and its history is therefore a history of politics and government. The tenth is the fact that the United States is a nation of scientists, and its history is therefore a history of knowledge and progress.

Wm. L. Garrison



NAVAL EXPERIMENTAL MODEL BASIN, CARDEROCK, MD.

View of building group looking northwest. June 21, 1939.



1. DAVID W. TAYLOR MODEL BASIN. JULY 1941.

General view of towing carriage 1 over the deep-water basin with a ship model attached to the towing dynamometer.



2. DAVID W. TAYLOR MODEL BASIN. MARCH 28, 1941.

Large model profiling machine in operation. Arm and vertical shaft of the Daniels planer may be seen in the foreground.



1. DAVID W. TAYLOR MODEL BASIN. AUGUST 20, 1941.

Weighing a ship model preparatory to ballasting it to the proper displacement, draft, and trim. All models as constructed are sufficiently light to permit adding ballast weights to make their weight correspond to the probable range of ship displacements.



2. DAVID W. TAYLOR MODEL BASIN

Placing ballast weights into ship model to obtain proper trim and even keel.



1. ENGINEER USING DYNAMOMETER FOR MEASURING MODEL RESISTANCE.



2. CAVITATING MODEL PROPELLER UNDER TEST IN 12-INCH WATER TUNNEL.

Picture made with $1/300000$ -second flash. Note heavy tip vortices, considerable laminar cavitation near tips, and the start of burbling cavitation of the blade face near the hub. This is a right-hand propeller and the water is flowing from left to right.

RESEARCH FOR AERONAUTICS—ITS PLANNING AND APPLICATION¹

By W. S. FARREN
Director, Royal Aircraft Establishment

INTRODUCTION

The exceptional circumstances of the times make it impossible for me to observe the letter of what I know is the Institute's wish in the choice of a subject, though I believe I can conform to it in spirit. The Institute desires that the lecturer shall deal with some scientific or technical subject on which he is, or has been, personally engaged, and shall not indulge in broad surveys. There will come a time when the lecturer's chief difficulty will be to choose from the embarrassingly rich store of knowledge which has accumulated during this war. But for the time being the door of that store cannot be opened in public. Moreover, I doubt whether the part that I have played in a large number of fascinating and exciting investigations during the last 4 or 5 years is such that I could fairly deprive those who have done the work of the privilege of speaking about it. This is a difficulty that has always faced those who hold such positions as mine, and one of which your Council were no doubt well aware when they invited me.

I have long been concerned with the problems that arise in applying the advances in knowledge which research for aeronautics has brought us and with the problems of planning the course of current research and of providing appropriate and timely resources for future research. I believe that these are matters that might with advantage be surveyed as a whole, in a scientific spirit. Moreover, I believe that the subject can usefully be treated in a purely personal way, and I have throughout drawn on my own experience.

From this it follows that any conclusions I draw apply only to the circumstances in my own country, or rather to my own interpretation of what they have been and may be. It will be for you, not for me, to say whether you find them in any way relevant to circumstances

¹ The seventh Wright Brothers lecture, presented before the Institute of the Aeronautical Sciences in the U. S. Chamber of Commerce Auditorium, Washington, D. C., December 17, 1943. Reprinted by permission from the *Journal of Aeronautical Sciences*, vol. 11, No. 2, April 1944.

in the United States. But the intimate relations that have existed between workers in America and in England, in the field in which my interests and responsibilities lie, give me the courage to believe that a summary of my experience may be of interest to you, and worthy of this occasion.

THE AIM OF RESEARCH

Research is one of the things we all understand but find difficult to define. In the foreword to a recent pamphlet on Industrial Research, Sir Harold Hartley defined it as "a habit of mind which makes us attack every problem, big or small, in an orderly, systematic way, using if possible the advantages that modern science can give us." I remember Lord Rutherford, in a characteristically expansive and emphatic mood, using almost the same words. I invite you to note the two words "if possible." There are limits to what "modern science" can do for us. In research, as in other human activities, we depend a good deal on our wits. There is limitless opportunity for intuition and initiative.

The aim of research is to produce a theory firmly supported by experimental evidence. Though necessarily incomplete, it must be a close enough approximation to serve the man who has to make things work. I trust you will not infer from this statement that I am interested in research only for what I can get out of it. I have known the thrill of working solely for the fun of it. But I am interested, for the time being, in research with a clear and unmistakable objective—the discovery of how to make better aircraft. It is my experience that, for such research to be not only fruitful but timely, it is essential that the practical problems involved in its eventual application shall always be clear to those who are doing it. This need not in any way restrict their freedom. Indeed, they can gain immensely from contact with those upon whom the burden of applying their work is placed.

The theme I have taken is indeed that it is only by intimate and wholehearted collaboration between the research worker, the designer, the constructor, and the user that research can be intelligently planned, pursued, and applied.

THE INDEPENDENT WORKER IN RESEARCH

As a preliminary I propose to give you an example from my earlier experience which I feel puts the point as it appears to the independent research worker.

I have been personally concerned with research in flight for nearly 30 years. The two chief aerodynamic problems have been, and still are, the reduction of drag and the improvement of stability and control. Throughout, these problems have been attacked in the light of

the practical questions thrown up by continuous contact, on the one hand, with those who design and build aircraft and, on the other, with those who use them. In my experience it has been this intimate relation between the three parties which has made this work so continuously exciting and, I believe, profitable. On looking back I cannot find any example that convinces me that we should have moved more quickly or more certainly had work on the fundamentals been divorced from that on problems of the moment.

It is true that at times, while we were developing our theory, we had the advantage—and this adds to my point—of individual work going on in flight, under conditions which I now believe to have been ideal. When I was one of the team who worked on these subjects at Cambridge, we often felt that we could do more, or do it more quickly, if only we had more of something—men, airplanes, workshops—but chiefly more hours in the day. In truth, I think we did as much as was physically possible without enlarging our organization, and, if we had done that, our work would have changed in character and would, I believe, have been less effective. That it had effect, and quickly, was due to our close relation with the establishments that had the necessary resources to exploit it for practical purposes with which they were intimately acquainted. They seized it and rapidly developed it. Its practical effect can now be seen not only in many aircraft but in the research equipment and programs of work.

You will remember Sir Melvill Jones's first Wright Brothers lecture, in which he described some of the work I have just referred to on the boundary layer. From my own share in that work I can say that we were profoundly excited by the problems themselves and by the fascination of trying to solve them by experiments in flight. But we were stimulated, and all our discussions were illuminated, by the realization of the potential application of their results. This we obtained from our constant personal contacts with the experimental establishments and with aircraft designers.

Thus my experience leads me to the conclusion that, while there should be no explicit attempt to divorce work on basic problems from that on immediate ones of narrower range, the fullest encouragement and practical support should be given to independent workers. What form this should take I hesitate to define. My own preference is not for large endowments to institutions in the hope that they may attract good men. I would rather make generous finance available through some semi-independent advisory organization when the need is made clear by the development of the work. This may be either in cash or in kind. We at Cambridge had very little money, but the country supplied us with airplanes and maintained and renewed them. My only concern is that the ponderous workings of the machinery of gov-

ernment, when finance is involved, may result in the essential help coming too late. One day we shall learn to trust our scientific advisers with a reasonable fraction of our money on a block-grant basis and ask no account except at longish intervals.

RESEARCH ON A LARGE SCALE

I come now to that class of research for aeronautics whose scale is such that success depends on planning of large experimental resources and on planning so that application to practice may meet the foreseen needs of design and its capacity to exploit new discoveries.

We must, in my view, plan research for aeronautics in three phases. First, we must relate all our main effort to advances in basic theory. Odd pieces of information without a clear, strong framework are worth little. Second, we must provide the experimental information by which theory may be built up and its limitations recognized and reduced. Third, we must ensure that experimental application is made in such conditions that the practical value of the theory is confirmed.

There are three chief parties to this undertaking: first, those who are by trade workers in the field of theory and those who have the flair for the associated exploration by experiment; second, those who make use of the results in the design and construction of aircraft; and third, those who use the aircraft and on whom we rely to exploit the product of the efforts of the first and second. The extent to which these should enter into planning of research can be illustrated by an example—the problem of reducing the cooling drag of power plants.

That it is possible to reduce the power wasted in cooling an airplane power plant to 2 percent or less of the brake horsepower was established many years ago. Indeed, it was shown that at flight speeds that were then within sight and have now been passed the cooling could be made to help to propel the airplane. But the cooling of a power plant is a matter that goes far beyond broad conceptions of this kind. It involves complex flows of air and liquids, demanding regulation to meet the varying conditions of flight and high standards of reliability in functioning and of ease of maintenance, which are of the greatest concern to the user.

It was not until other developments had reduced the rest of the drag so much that the power-plant drag was a dominating factor that the designer became convinced that the problem demanded his serious attention. He has finally succeeded in producing cooling systems that are no less reliable and have a much lower drag. The user accepts the slight additional embarrassment to maintenance in return for the higher speed and greater range.

But the practical problems of achieving the full result are still only partially solved. Few power plants will stand up to critical examination on such points as low-loss ducting or airtight cowlings. It is a difficult engineering problem to design and make such features at the same time light and easily removable and replaceable without damage.

Throughout the whole history of this development there has been intimate association between the three parties chiefly concerned. But in my view we can now see that a better planning of the enterprise as a whole would have saved much time and waste of work. In particular, an earlier realization by the designer of the outstanding advance that was within his grasp would have brought him to a closer cooperation, on strictly practical lines, with his only source of specific information—the research establishments. They in turn were backward in that they did not provide themselves with the right material by which alone convincing information, directly applicable to practical problems, could be obtained. This is a case in which I believe the enlightened user, if correctly advised, could have forced the pace.

A SURVEY OF 25 YEARS' ACHIEVEMENT

The final criterion of our success in using the knowledge with which we have been supplied is the extent to which the product of our efforts has improved as time has passed. The curve of advance is not a smooth one. Over longish periods we often see little beyond a slow rise in achievement, and we tend to believe that there is little more to be expected. Then there comes something in the nature of a transformation. It is often ascribed to a single cause and, generally, one can say that there is an outstanding stimulus. But if we compare the final product—in this case, the airplane itself—before and after the event, allowing a long enough time for the situation to reach a fairly stable state, we can make a fair assessment of the relative weight of all the influences which have contributed to the change. I believe such an examination of the advance of the airplane between say 1917 and 1942 is useful in providing us not only with a means of examining how far we have been successful in using the results of research but also a guide to the part played by sheer engineering skill and initiative. Finally, it may serve as a base from which we may survey some of the potential advances that are now opening out to us and judge what resources we shall need in order to achieve them.

I shall take two typical aircraft that were in general and successful use in 1917 and compare them with two modern aircraft of similar duties. Naturally there are striking differences, and we shall find no difficulty in tracing them to their sources. But perhaps equally striking are the characteristics that have apparently undergone little

change. I think, however, that we shall see that the effort to preserve them unchanged has made as high a demand on research and engineering skill as that required to produce the more obvious improvements.

During the last war the Royal Aircraft Factory (which became the Royal Aircraft Establishment in April 1918) produced many designs for aircraft which were constructed in large numbers. One of the most successful was the S. E. 5, a single-seat fighter with a 180-hp. Hispano Suiza engine. It had a creditable history as a fighter. I propose to compare it with a Spitfire. Then I shall take the Handley Page 0/400 twin-engined heavy bomber and compare it with a Lancaster.

I shall not be giving away any information to our enemies. They are well acquainted, in more ways than one, with both Spitfires and Lancasters. Some of them may even remember the S. E. 5 and the 0/400. For my purpose it is quite sufficient to take examples of marks of the modern types whose performance has long been surpassed.

Let us first look at them in general outline. Figure 1 shows the 1917 fighter. In Figure 2 its specifically military features have disappeared and around it is the outline of the Schneider Trophy streamlined monoplane, the essential product of the period between the two world wars. Figure 3 shows the 1942 fighter. In Figures 4, 5, and 6 is shown the transition from the 1917 bomber, through the streamlined airliner, to the 1942 bomber. The most obvious differences are the change from biplane to monoplane and the general cleaning-up due to enclosing the crew, abolishing external wing bracing, and retracting the undercarriage. Comparing them type by type, the over-all dimensions are not very different. The Spitfire has the same wing surface as the S.E.5, about half the drag, nearly twice the strength, three times the speed, four times the total weight, four times the military load, and seven times the power. The Lancaster has about half the drag of the Handley Page 0/400 on the same span of wings and about three-quarters the wing surface. Its total weight is nearly five times as great; the wing loading, over six times; the power, seven times; and the military load, with a 25 percent greater range, over eight times. Let us inquire how some of these improvements have been made.

DRAG REDUCTION

The change in drag coefficient C_D is of first interest. I have not found it possible to get accurate figures for the older aircraft, but they are approximately 0.039 for the fighter and 0.046 for the bomber. The corresponding modern figures are 0.022 for the Spitfire and 0.030 for the Lancaster. Thus, per square foot of wing surface, the total drag has been reduced to about 55 and 65 percent of the 1917 standard.

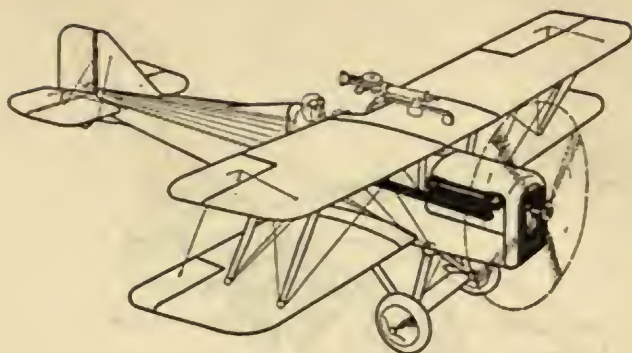


FIGURE 1.

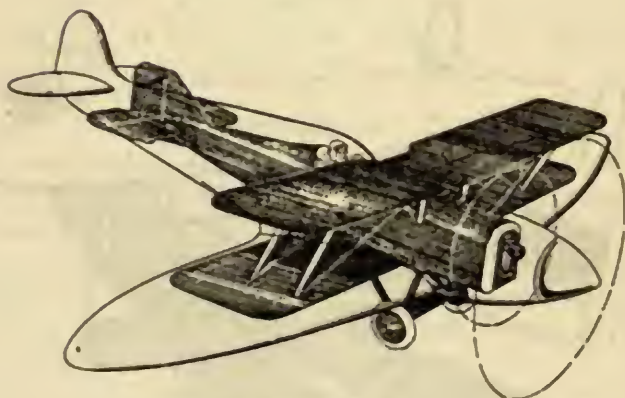


FIGURE 2.

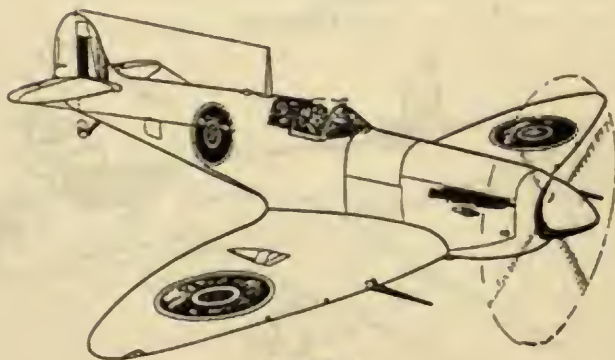


FIGURE 3.

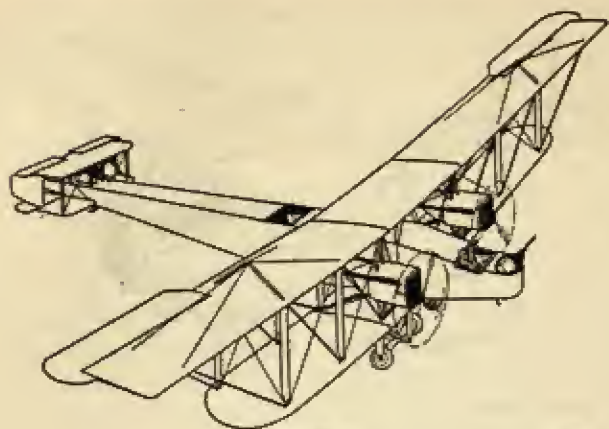


FIGURE 4.

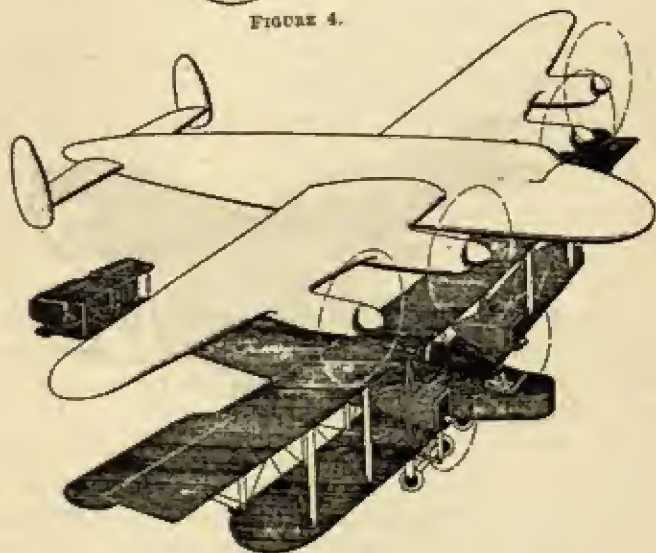


FIGURE 5.

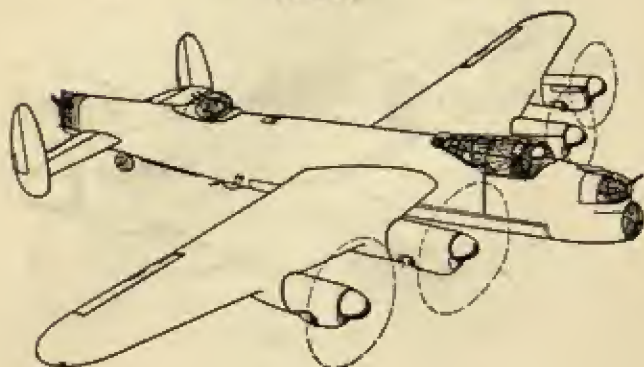


FIGURE 6.

Comparing the two fighters in more detail, we find first that the wing surface is the same for both. Disregarding induced drag (or assuming it to be the same fraction of the whole in each), the top speed at the same height will be proportional to the cube root of the thrust power divided by the drag coefficient. Since the propeller efficiency is near enough the same for both, we may use brake power. Taking ground-level powers in both cases—180 hp. for the Hispano and 1,250 for the Merlin—the ratio is about 7. Thus the contributions to increase of speed are:

$$\text{by reduction of drag } \left(\frac{0.039}{0.022} \right)^{1/3} = 1.21$$

$$\text{by increase of power } (7)^{1/3} = 1.92$$

The product of these figures is 2.33.

If we assume that by supercharging it is possible to keep the Merlin power constant up to say 25,000 feet, where the density is approximately halved, we shall get a further rise:

$$\text{by supercharging } (2)^{1/3} = 1.26$$

The total ratio of increase is therefore nearly 3.

At this point I feel that the engine people are feeling very pleased—and we have good reason to acknowledge the success of their effort. But these figures as they stand do less than justice to the aerodynamic contribution. All the cooling required by the seven-times increased power has been provided and yet the aircraft has no more than half the drag per square foot of wetted surface.

How have these improvements been made? Let us look first at the drag account (table 1). To the saving of 47 pounds, the most obvious contributions are from the elimination of wing bracing and undercarriage—31 pounds in all. But the body and cooling drag is actually reduced by over 10 percent in spite of the sevenfold increase of power.

TABLE 1

	S. E. 5 drag at 100 ft. per sec.	Spitfire drag at 100 ft. per sec.
	Pounds	Pounds
Wings.....	28	20
Wing bracing.....	15	.....
Body and cooling.....	44	38.6
Tail surfaces.....	7	4.4
Undercarriage.....	16	.....
Total.....	110	63
Cps.....	0.039	0.022

TABLE 2

	S. E. 5	Spitfire	FW 190
	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
Structure.....	29.7	28.9	30.9
Power plant.....	37.1	38.0	35.7
Fuel.....	15.4	16.6	14.3
Load.....	17.8	16.5	19.1
Total.....	100.0	100.0	100.0
Primary load factor.....	6	10	-----

For the bomber, the reduction in C_{D_0} is rather less than for the fighter on account of the drag of defensive armament, but otherwise the influences operating have been much the same.

Toward the end of my paper I shall say something about what further improvements in drag are in sight and what problems we have to solve in order to achieve them.

WEIGHT ANALYSIS

Let us look next at the weight picture. The Spitfire weighs four times as much as the S. E. 5; the Lancaster, nearly five times as much as the 0/400. What has made it possible to carry so much additional weight per square foot of wing surface—for the fighter four times, for the bomber six times as much? In the airplane itself, first, the development of flaps giving higher maximum lift coefficient and higher drag; second, power plants of much greater power per unit weight; and, third, constant-speed propellers to make the power fully available over a wide speed range. But larger and better airfields, permitting higher take-off and landing speeds and better flying technique, have contributed even more. The effective maximum lift coefficient has risen by about 65 percent. Even so, the touch-down and take-off speeds, with the higher wing loadings, are 50 to 80 percent higher.

A comparison of the weight analyses and load factors of the fighters is given in table 2. As a matter of interest, I have given also the weight analysis for the FW 190.

How has this remarkable similarity of weight distribution been maintained? From the structural point of view, it is essentially by increasing wing loading four times that it has been possible to go from braced biplane to monoplane with nearly double the primary strength, from fabric covering to a metal skin, and from a fixed to a retractable undercarriage with no significant changes in percentage structure weight.

From the point of view of the power plant, we have to record a rise in the net output per pound of complete plant in the ratio of about 7 to 4. The complete plant of 1942 includes both constant-speed pro-

PELLER and supercharging arrangements by which the power is maintained up to heights at which the air density is half, or even less than half, of that at ground level.

For the same percentage fuel weight the range is some 40 percent better at a much higher cruising speed. Specific fuel consumption is much the same in spite of the great improvement in specific performance achieved in the face of the burden of supercharging. We must acknowledge here the tremendous contribution of high-octane fuel.

We are left in both cases with about one-sixth of the total weight for the man, his equipment, and armament. The weight of the man is the same as it was. In 1918 it exceeded that of his whole fighting equipment. Today it is but a fraction of it. The weight of the bullets alone in the modern fighter exceeds that of the whole armament of the S. E. 5.

For the bombers, weight analyses are strikingly different from those of the fighters (table 3). In 1917 we thought it natural for the structure weight of a large bomber to be greater than that of a small fighter—40.4 percent compared with 29.7 percent. In fact there was a view, widely held and expressed somewhat forcibly by Dr. Lancaster, that aircraft of larger span than say 100 feet would be uneconomical because of the operation of the square-cube law characteristic of geometrically similar structures. Designers, aided by research, have managed to avoid the consequences of this law. They have been so successful that the structure weight percentage for the Lancaster is practically the same as that for the Spitfire. The load factor of the bomber is, of course, much lower than that of the fighter. But it is probably little different from that of the 1917 bomber. The progress that has been made is therefore remarkable.

TABLE 3

	Handley Page 0/400	Lancaster
	<i>Percent</i>	<i>Percent</i>
Structure.....	40.4	31.4
Power plant.....	22.0	16.4
Fuel.....	19.3	19.8
Load.....	18.3	22.4
Total.....	100.0	100.0

In the achievements summarized above I think aerodynamic, structural, and power-plant improvements can fairly claim about equal shares, and to each, I suggest, the contributions of research and of engineering skill and ingenuity have been about equal. To pursue the analysis would lead me away from my main theme. But I think we may, with advantage, examine the history of effort in the structural and

aerodynamic fields a little further in order to show the nature of the difficulties that have been met and the methods by which they have been overcome.

STRUCTURAL DEVELOPMENTS

In 1917 the great majority of aircraft structures were made of wood and steel. Light alloys were little used. Wing surfaces were covered with fabric, and torsional stiffness requirements were met by the bi-plane wing structure. Today, with few exceptions, we use light alloy for the primary structure, and torsional stiffness is derived in most cases from the light-alloy sheet wing covering. The very considerable improvement that has been made in aluminum-rich alloys contributes chiefly to the wing spars. There is as yet no marked sign of a development in their properties or application which will reduce the weight involved in meeting torsional stiffness requirements. This is, of course, because these involve stability rather than strength characteristics.

I do not suggest that the enormous effort that has been put into improving aircraft materials has not contributed to the maintenance of structure weight at a remarkably low figure in spite of increases of speed, strength requirements, and size. But it is significant that the Mosquito airplane, which is made almost entirely of wood, has a structure weight as low as that of the equivalent metal airplane.

One feature of the modern aircraft which has undoubtedly contributed to a more economical wing structure, in particular, is the great increase of wing loading and therefore of wing weight per unit area, which has made it possible to employ the material to much greater advantage—i. e., to have a smaller percentage of relatively lowly stressed material. This brings me to one of the outstanding contributions of research to aeronautics—namely, that derived from the investigation of the strength of actual structures in close association with theoretic analysis. It is by such work that it has been possible to increase greatly the useful load of practically all aircraft now in use. The most thorough mechanical testing of aircraft structures undoubtedly pays a high dividend. These tests have not only shown us that our methods of design have led to general forms of structure well adapted to meet the demands on them, and fundamentally economical in character, but have enabled us to discover where our knowledge of the detailed distribution of stresses is inadequate and at the same time to improve that knowledge and to strengthen the structure against unforeseen local weaknesses.

The determination of the loads that the structure is called upon to bear is fundamentally a more difficult problem. We are greatly indebted to such methods as the V. G. recorder, but these give us only over-all figures that, useful as they are, throw little light on the load

distribution in flight. We have now available a method of great potency in the electrical resistance strain gauge. This is being used with great effect on a large scale in laboratory tests, and its application to measurements in flight is being rapidly developed. It will undoubtedly prove to be one of the greatest contributions of the research worker to improvement in the structures of aircraft.

Possibly the greatest achievement of the research worker in the field of aircraft structures is in discovering how to avoid the dangers of what we comprise in the term "flutter." In my view, there is in the whole of aircraft engineering no better example of the power of mathematical analysis, of ingenuity in experiment, and of skill in interpretation. The successful attainment of very high speeds, with a remarkably small number of serious failures, can only be ascribed to the most skilled use of all these resources, guided by systematic review of the results of their application. Direct experiment in flight—the only satisfactory check—is almost impracticable. Laboratory determination of reliable numerical values of the essential quantities involved is extremely difficult. Much more information on these is essential for progress, and here the designer can justifiably demand all that research can provide.

STABILITY AND CONTROL

Up to this point I have said nothing of the contribution of research to the production of stable and controllable aircraft. I am glad to say that the time is now long past when lack of stability is regarded by anyone as a virtue in an aircraft. In fact it is unquestionably a most serious defect, whatever the duty of the aircraft. But it has always been difficult to define the necessary or desirable margins of stability and the associated general stability and control characteristics. The designer must, however, have the requirements expressed in terms that can be reflected in his lay-out, both as a whole and in detail. He must be able to judge fairly accurately how the changes inevitable as a design develops will react on the stability and control, and he must have at his disposal means of dealing economically with the consequences both of the variation of load distribution resulting from operational conditions and of the changes involved in the development of the aircraft.

There is a good deal about the stability and control of aircraft in which there has been little apparent change over the period covered by the examples I have taken. I believe, however, that this is simply because the desirable general characteristics were attained by about 1918. Since then our main problems have been, first, to preserve them substantially unchanged in spite of the profound changes in the form of aircraft and, second, to enable the same man to control much larger and much faster aircraft.

The foundations of stability and control theory were laid, and well laid, long ago. Much labor has been spent on expanding it to embrace new developments, such as structural distortion, and on the analysis of the controlled and uncontrolled motion of aircraft. A vast amount of experimental evidence has been accumulated. Much of this, however, is related rather to specific problems than to the systematic development of an understanding of the matter. There is room here for a wholesale improvement, particularly by an attack on a wider front in flight. I am not among those who criticize our record here on the grounds that we did not undertake enough basic work at the time when the airplane, as we now know it, first crystallized. I regret that circumstances made it impossible to give this work high priority. Had we been able to do so, we might have avoided many troubles and saved much labor. But I do not believe that, on the balance, we would have reached our objective—usable aircraft—more quickly. We relied on our past experience, on our ability to improvise, and—most significant of all—on our conviction that the theory available was soundly founded on experimental evidence. We discovered, by the attacks we were forced to make on troubles as they arose, much more about stability and control than most of us believed there was to learn. Thus, and I believe only thus, could we have advanced at the rate we did. It is an excellent example of the interworking of research and application.

In the field of control balance we have made tremendous advances in the face of difficulties that are sometimes hardly appreciated. The 1917 bomber operated at speeds—80 to 100 m.p.h.—at which the pilot could provide the forces necessary for control with little or no aerodynamic balance. Take the 0/400 ailerons. The maximum hinge moment required was probably equivalent to a force on the pilot's hand of the order of 50 pounds, with ailerons on which the aerodynamic balance was probably no better than one-half. In the Lancaster the same movement of surfaces of about the same size is required at 300 m.p.h., requiring nine times the forces. The pilot is no stronger, so the aerodynamic balance must reduce the hinge moment to say one-eighteenth of that of unbalanced ailerons. This is a difficult requirement but it has been met.

Suppose we put up the weight at the same wing loading to 100,000 pounds, one and one-half times that of the Lancaster. The linear dimensions will rise in the ratio $1.5^{1/2}$ and the hinge moment at the same speed in the ratio $1.5^{3/2}$. The aerodynamic balance must therefore reduce the hinge moment in the ratio

$$1/(2)(1.5)^{3/2}(3)^2 = 1/30$$

A similar argument leads to a figure of 1/400 if the weight is increased to 500,000 pounds. We can certainly achieve 1/30 and possibly 1/400

in ideal conditions. But it is doubtful whether this is a wise policy, since we can hardly expect to define or to maintain the shapes of surfaces sufficiently closely. Power-operated controls have been avoided so far, but it is unwise to assume that we can neglect them indefinitely. There seems to be no good reason to be doubtful of our ability to make them reliable.

POWER-PLANT DEVELOPMENTS

I do not propose to extend this survey to the two other main factors that have contributed to the changes we have seen in aircraft—the power plant and the propeller. I have already quoted some figures that show how remarkably the reciprocating engine has advanced. I have also said that there have since been further advances, which, however, serve rather to emphasize the comparisons I have made than to invalidate them. This is because there have been accompanying changes in weight and other characteristics that leave the main conclusions substantially unaffected. Our debt to the engineers who, aided by research, have achieved these results is immense.

To the constant-speed propeller the performance of aircraft must also acknowledge a great debt. But the flying man is even more grateful for what it has provided—almost complete freedom from his chief anxiety, namely, the liability to misuse his engine. We now look forward confidently to new methods of propulsion for aircraft. But I believe the propeller has a long and useful future before it and one in which research will play an outstanding part.

SUMMARY—THE TASK OF RESEARCH

I trust that this short survey has gone some way to show why I am convinced that the research worker and the engineer must work together if we are to make significant progress. In his James Forrest lecture to the Institution of Civil Engineers in England, Dr. Southwell said that "Aeronautical engineering is ordinary engineering made more difficult." If that was true in 1930, as I believe it was, it is more than ever true now. We can see clear prospects of great advances in aircraft in size, in performance, and in safety. The curve of improvement against time shows no real signs of flattening out. But we shall need all our ingenuity to avoid or to overcome the barriers which we can see ahead.

I think the engineer has made good use of the outstanding contributions of research for aeronautics. If at times he has appeared slow to appreciate the significance of new developments, he has a good excuse in his preoccupation with producing something on which we can rely. This is a sufficiently serious responsibility and one that he has borne with credit. But it is this very preoccupation that emphasizes the need

for employing as part of an engineering organization men competent to detect those advances in knowledge which are potentially valuable and to work out the technique of applying them.

The research worker himself is not blameless in this respect. We can call to mind the case of Mendel, the significance of whose work in genetics was not recognized until he had been dead many years. His case is an example of discovery not appreciated because it is too far in advance of the general state of development of the science. Dr. Lancaster's books *Aerodionetics* and *Aerodynamics* contained much which may perhaps be regarded in the same way.

The instances I have mentioned may, of course, be regarded as classic examples of the difficulty of disseminating knowledge. As the volume of knowledge increases, this difficulty grows. In the hall of Trinity College, Cambridge, there hangs the portrait of William Whewell, sometime Master. It is said that he was the last man to know all knowledge. He died in 1866.²

But the research worker has, in my view, a part to play in "putting across" the results of research. It is reasonable to ask that he should put his results in such a form that they can be used. To those who feel that this is hardly worthy of so much of their time and attention, as it certainly demands if it is to be well done, I would command the example of one of the greatest workers in aeronautics, Hermann Glauert. Every one of his outstanding contributions to aerodynamics was finished in such a form that the method of its application was made clear. I am not aware that this in any way detracted from the value of his work on whatever basis it may be judged. And I know, from my long and intimate friendship with him, that he regarded it as the natural method, and indeed the only one that would satisfy his sense of craftsmanship.

PROBLEMS OF THE IMMEDIATE FUTURE

If this review leaves us confident of our powers to use effectively the results that an alliance between research and engineering ingenuity can provide, as I think it should, how should we shape our plans for the future? Let us look for a moment into what the future may hold for us in one field alone: still further improvement in performance—in speed and in range.

Within the limits of our present knowledge the most economical way to fly faster is to fly higher. Let us suppose that we can extend

² Oxford may feel that their claim has been overlooked. It is preserved in the rhyme:

My name is Benjamin Jowett
Everything that's known, I know it.
What I don't know isn't knowledge
And I am Master of Balliol College.

Jowett died in 1893.

the range of operation of power plants so that propulsive power is independent of height. Taking an airplane with the characteristics of the Spitfire (table 1), and assuming that $C_{D0}=0.022$ under all conditions, the curve of speed against height is shown in figure 7 labeled *A*. The line of sonic speed, Mach number=1, is crossed at 65,000 feet. In practice the effect of the compressibility of air begins to be felt at about $M=0.65$ at 33,000 feet at a speed of about 430 m.p.h., and the rapid rise of C_{D0} with M brings the curve for greater heights down to about the level of curve *A*₁. The loss of speed is very large.

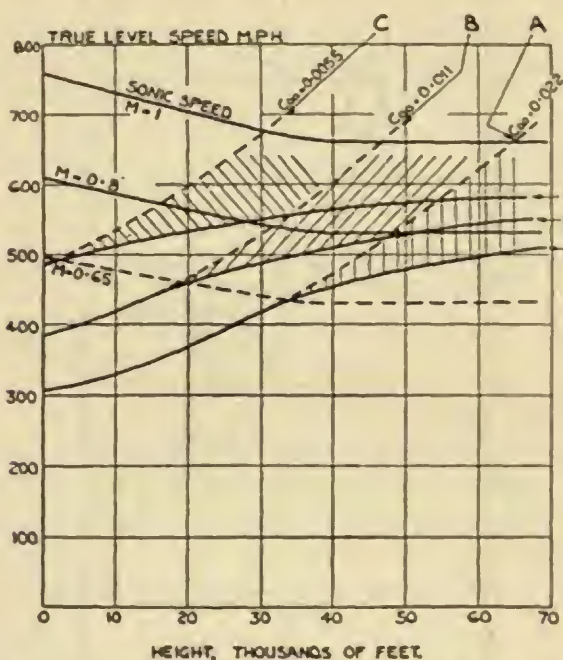


FIGURE 7.—True level speed vs. height, showing influence of reduction of C_{D0} and of compressibility. Propulsive power, 4.5 T. H. P./sq. ft. wing surface; wing loading, 28 lbs./sq. ft.; aspect ratio, 5.6.

If, by devising forms that will ensure some measure of laminar flow, we can halve C_{D0} and at the same time avoid compressibility effects, we get curve *B*. But if compressibility has the same kind of effect as on the original airplane, the result will be to depress the speed to curve *B*₁. Similarly, reducing C_{D0} to one quarter of the original value, we get curves *C* and *C*₁.

If we are to reach really high speeds economically, it is clear that we must devote at least as much effort to avoiding or reducing the effect of compressibility as to reducing the "low speed" value of C_{D0} . On the other hand, at speeds at which it is likely to be economical

to cruise for long distances, compressibility will for some time be relatively unimportant and laminar-flow forms offer outstanding prospects. In round figures range and economical cruising speed are inversely proportional to the square root of C_{D0} . If we can halve C_{D0} , both range and cruising speed will rise by 40 percent.

We must not dismiss too lightly the possibility of cruising economically, at great height, at very high speeds—speeds at which com-

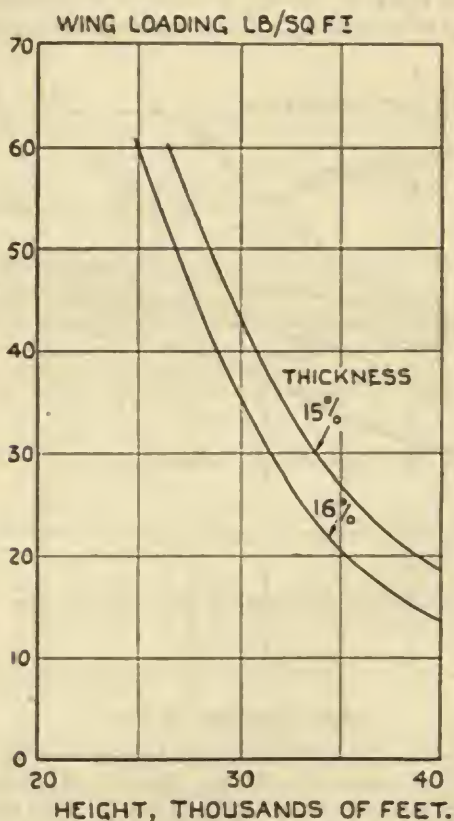


FIGURE 8.—Critical wing loading vs. height. True level speed 450 m. p. h.; flow laminar up to 60 percent of chord; airfoil thickness 15 to 16 percent.

pressibility may well have a dominating influence on design. With a laminar flow extending over the majority of the surface of the airplane we may reasonably expect to be able to cruise at 450 m.p.h.—a Mach number of about 0.7. Considering the airfoil alone, because of necessary thickness and camber, sonic speed will occur at a point near the surface when the lift coefficient reaches a certain value. Hence, the wing loading must not exceed a figure dependent on the

height. At the heights at which it is likely that such speeds will be economical, from the power aspect, calculation suggests that rather low wing loadings will be required. Figure 8 shows the results of some preliminary calculations on this point. The wing loading corresponding to the critical conditions is sensitive both to airfoil thickness and to height. For example, assuming 60 percent of laminar flow, 15-percent thickness, and a camber appropriate to the lift coefficient, the critical wing loading at 35,000 feet is 28 pounds per square foot; or for a 16-percent thickness, 20 pounds per square foot. At 30,000 feet the corresponding loadings are 44 and 35. If these calculations are sound, the effect on the general economics of the situation will be marked. Here is another reason to justify extensive theoretic and experimental work in this field.

Thus we see both the barriers to progress which now face us and the potential rewards that will be ours if we can succeed in surmounting them. I return to my main theme—the research worker, the designer, the constructor, and the user must join forces and, each fortified by the confidence and help of the others, plan the work that is needed to provide the information, pursue the investigations in the conviction that the aim is worthy of the effort demanded, and apply the results to produce better airplanes.

From aerodynamics we demand not merely the bare solution of the problem of forms providing laminar flow, relatively immune from effects of compressibility. We require specific information covering the whole airplane, including its propulsion, stability, and control. It may be that the whole lay-out of the aircraft will be different from that to which we have been accustomed. It is for the aerodynamic people to say, but they must base their opinions on a sound foundation of experiment.

From structural research we require to know what schemes of structural design are most likely to provide the necessary precision of form and superficial smoothness and how to cope with new strength and stiffness requirements. Aerodynamics must supply information on the loads that will be met in flight, and much thought must be given to the meteorologic conditions that will be encountered.

In the future it will be impossible to consider the airplane engine and the airplane as separate enterprises with conflicting requirements. The thermodynamic problems will be aerodynamic also. Their joint solution will throw up more than enough of the design problems at which the power-plant engineer excels.

Will the transformation of the energy of the fuel into thrust demand a propeller or a jet or a combination? There is no single answer. It will depend on the duty of the airplane. But the propeller designer will find that his task will tax all his ingenuity.

Upon the airplane designer will fall the burden of combining into a working proposition the contributions of all his collaborators. He will need to provide for pressurized cabins, ice-free surfaces, and the many indispensable aids to control, navigation, take-off, and landing.

To the user the prospects are such that he should spare no pains in encouraging the research worker and the engineer in their difficult tasks. He must support them to the full in obtaining the resources, in men and material, which will be essential for solving their problems. And he must contribute, as a member of the team, the operational information that will guide their efforts at all stages.

The experimental resources that such work demands are large. They must be generously planned to provide the greatest possible scope and flexibility. It will take time to devise and to create them, and during this time we shall inevitably meet further difficulties whose exact nature we cannot yet foresee. We may be confident in our ability to adapt and to improvise, but we must ensure that the basic equipment is on an adequate scale.

THE MANAGEMENT OF RESEARCH FOR AERONAUTICS

I have left until last such remarks as I have to make on an aspect of planning research for aeronautics to which you may feel I should have paid more attention—namely, the organization and management of the work on the scale that the scope and complexity of the problems demand. In what I said earlier I have emphasized my belief in the value of the independent small team of workers, who necessarily work on a small scale with relatively small equipment, and on one or at most a few problems. But we must recognize, perhaps reluctantly, that we have problems to solve which cannot be handled successfully in that way.

It is not merely the large size and complexity of the equipment required which forces us to face the task of managing large research undertakings. It is rather that the many problems we must attack are interdependent, and that success in dealing with them depends on assembling and coordinating the efforts not only of a team but of many teams of workers. As in any large undertaking we have to break the work down into parts. Each part is the primary responsibility of a group of specialists under a leader. But the parts must be welded into a whole, and in this welding lies the problem of management.

I believe that the problem is best approached not from the top but from the bottom—from the point of view of the individual member of a team. What does he need in order that he may do the best that is in him? In my experience, he needs the following:

(1) A clear, unambiguous statement of the ultimate objective. This must be more than a statement of the specific problem. It must relate it to the general picture of which it is a part. Thus he will know *why* the work is being done.

(2) An opportunity to give his own views on the value of the underlying ideas. The basic plan must be, in part, his own. Thus he will start with a sound conviction that the plan is a good one.

(3) An immediate leader in whom he has confidence, who will inspire him, help him, and keep him up to date in all the relevant parallel work on related problems. Thus he will retain the good spirits in which he starts.

(4) Sufficient resources to enable his work to progress at what is, in his judgment, a speed commensurate with the importance of the objective. Thus he will feel that the value of his work is recognized in the only way that means anything to him.

This formula can, in my experience, be applied to groups of workers under a central management or to separate establishments under a central direction. And the difficulties that one meets in applying it arise not from its shortcomings but from conscious or unconscious neglect of its essentials.

Looked at in this way, such questions as the ideal size of research establishments cease to be of any great significance. Just as a team must have a leader who knows all about the work being done by its members, so a group of teams must have a leader who is recognized by them to know enough about their work for him to be able to guide it to its common objective. The limit of economical size of a complete unit is set not by some arbitrary formula but by the simple fact that no one man can know enough about work in more than a few fields to be able to inspire real confidence in his team leaders or their teams. The control of large equipment, the management of numbers of skilled industrials, and the commonplace daily problems of facilities are matters of consequence, but they are not the real determining factors. In any event they are well understood and can be broken down and shared among a properly balanced staff.

I would summarize my views on this question as follows. There is no single or simple formula by which to determine the best method of handling research. But I believe there are a few simple principles in the light of which each particular situation may be reviewed and a good solution found.

CONCLUSION

You will see that my experience has led me to the view that the record of science and engineering in aeronautics is a creditable one. It justifies us in demanding the means of extending our efforts into

those new fields that we can now clearly see. The task of organizing and managing the work, of devising and constructing the equipment, and, above all, of leading those upon whose efforts success will in the end depend is one of absorbing interest.

What the world will make of our efforts is a matter on which I regard it as unprofitable to speculate, at any rate here and at this time. I am an engineer in a world where good engineering, skillfully used, means survival and bad engineering means the end of what I believe to be a good way of living. So I am content for the time being to confine my efforts to the work in hand and to leave philosophic speculations on its value, on some absolute scale which I confess eludes me, to those who can find time or inclination for it. For this reason I have confined my attention primarily to research for aeronautics as used in war. There is another reason—I have spent the best part of my life on work with this as its first aim in the conviction that it had to be done.

But I am an incurable optimist. I believe that we shall succeed in our present effort—in which the share of research is to provide information by which aircraft and their equipment can be steadily improved and used to greater effect. When we have achieved our immediate aim, I do not doubt that much of our work will be put to uses that are more to my taste and to yours.

In the end, however, it is with the scientific and technical advances in the means of flight that we are here concerned. So far we have had a mere 40 years in which to show what we can do. It has been my purpose to point, in the light of my experience, to what we must do now to discharge the responsibility that is laid on us so that those who will follow us may find a fair field in which to explore the endless vista of opportunity which will lie before them.

HUMAN LIMITS IN FLIGHT¹

By BRYAN H. C. MATTHEWS, C. B. E., M. A., SC. D., F. R. S.

*Head of the R. A. F. Physiological Laboratory, Consultant in Physiology
to the R. A. F.*

[With 3 plates]

A modern aircraft will climb in a few minutes to heights at which the air is so thin that it will no longer support life. It can turn and maneuver so fast that the pilot may easily be rendered unconscious from the mechanical forces which it imposes on his body, and in an aircraft which is moving rapidly in three planes of space the pilot can be subjected to stresses beyond the limits which the human body can stand.

The adaptation of which the human body is capable to new surroundings and conditions can play a considerable part in fitting man to these new conditions; for example, airsickness which many suffer on first flying in rough air or doing aerobatics, in most people soon passes off and they become adapted to motions which at first perplex and incapacitate them, though a few never become completely adapted. But there are several stresses placed on man in aircraft that cannot be met by any unconscious adaptation, which require equipment specially designed to meet them. Some of the necessities are obvious, such as windcreens to protect the man from the great wind pressures at high speed and a heat supply from the engine or special clothing to keep him warm in the Arctic cold of the stratosphere. His senses must be extended by a set of blind-flying instruments so that he may know his altitude and movement in space when in clouds or at night. He must learn to believe the instruments against his senses for these are no longer a reliable guide when he may be moving at varying speeds in any direction, in fact they will often be wrong. The human limit of visual range by day and especially by night is of paramount importance in flying.

But beside the stresses from wind pressure, cold, vibration, and noise, the pilot's body must also be protected from other less obvious stresses and here I propose to deal particularly with the two greatest

¹ Reprinted by permission from the Proceedings of the Royal Institution of Great Britain, vol. 22, pt. 3, 1943.

stresses which an aircraft puts upon the pilot—those due to acceleration or rapid change of motion and those due to high flying in the rarefied air of the upper atmosphere.

In the last hundred years man has increased the speed at which he can travel more than tenfold, but there is no reason to suppose he is approaching any human limit in speed for, provided that he is protected from wind pressure by a closed cockpit and that the motion does not change rapidly in direction, there is no more mechanical stress on the pilot than if he were sitting on the ground.

If the human body is moving uniformly there is no force acting on it other than that due to gravity, recognized as weight. But when the motion changes in either magnitude or direction, large forces come into play; for example, while launching an airplane by catapult. During this linear acceleration the pilot has the sensation of being driven backward against his seat by forces equaling several times his own weight. This is seen in the retracting of the skin of his face which bares the teeth like a snarling dog. In this case, the acceleration acts transversely on the body and lasts only a few seconds and in this direction the pilot can easily withstand many times the acceleration of gravity provided his head and shoulders are well supported.

When a fast-moving airplane changes its direction and turns, airplane and pilot are both subjected to very large forces. The phenomenon known as blacking-out came into prominence in the Schneider Trophy races; pilots found that in turning at high speed their vision became blurred and that for a few seconds in the turn they frequently became blind. This is now a common event in aircraft and is well understood by fighter pilots.

When an airplane travels in a curved path in turning or pulling out of a dive a large centrifugal force tends to force the airplane and pilot away from the center of the circle. The magnitude of this force increases with the square of the speed and decreases as the radius increases. Subjectively, a pilot experiences a great increase in weight of all parts of his body as the centrifugal force tries to drive his body out through the bottom of the airplane. The magnitude of the acceleration acting on the pilot is expressed in terms of g , the force due to gravity normally acting on the body which causes it to have its normal weight. Thus in a turn producing $4g$ or four times the force of gravity, if the pilot's seat were fixed to a spring balance it would register four times his normal weight and the pilot and all parts of his body become extremely heavy. This is seen in the sagging of the soft part of the face which occurs in a tight turn (pl. 1). A turn at 300 miles per hour and 1,000 feet radius produces $6g$, and a pilot in effect weighs about half a ton and his blood virtually becomes as heavy as molten iron. The blood is normally being pumped to the pilot's head by his

heart but as its virtual weight increases the heart has difficulty in maintaining the blood supply to the head. The brain and the eyes can only function for a few seconds without their normal blood supply and loss of vision in blacking-out is due to failure of the circulation in the retina of the eye. If the acceleration is still greater, the whole blood supply of the brain fails and the pilot becomes unconscious.

Blacking-out is a warning that the blood pressure in the cerebral arteries is getting low. If the control column is eased forward, the airplane straightens out, the centrifugal force ceases and within a few

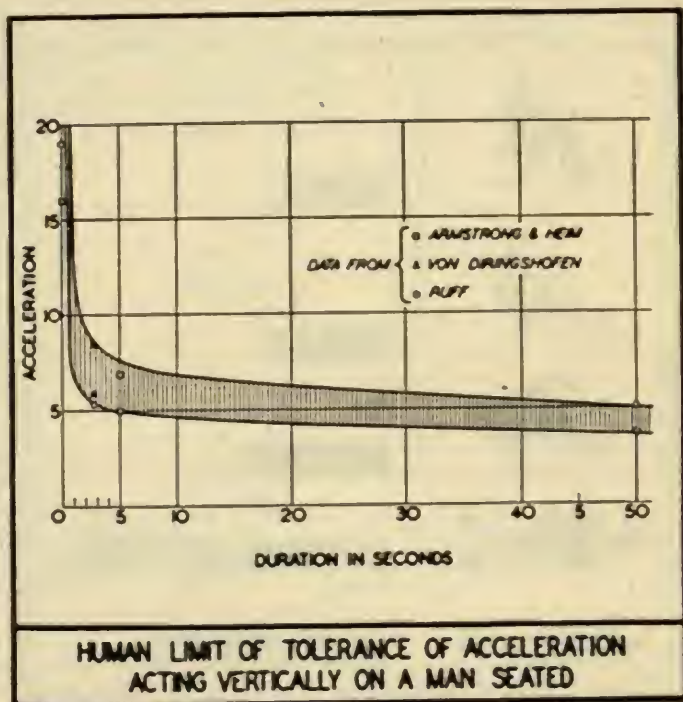


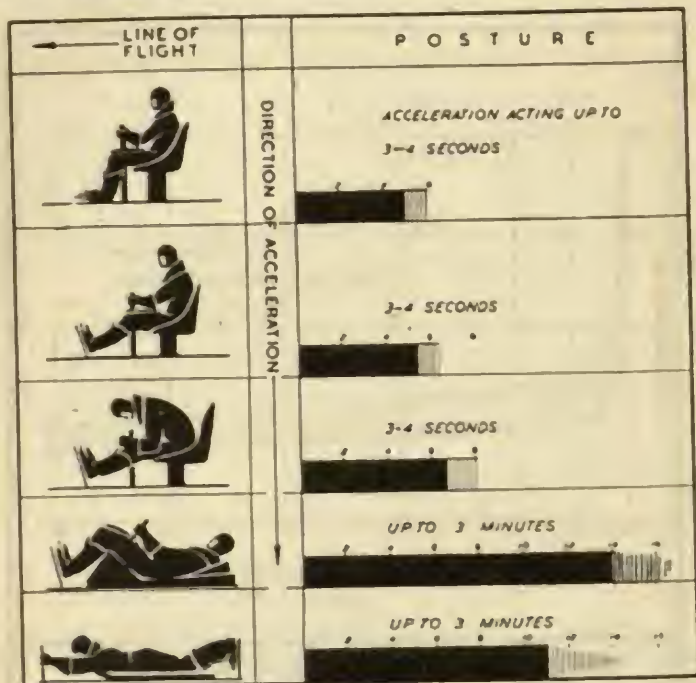
FIGURE 1.—Approximate relationship between duration of varying degrees of acceleration and occurrence of loss of vision (lower curve) and loss of consciousness (upper curve). (Data from various sources.)

seconds the circulation returns to normal. While this happens in the head the deficit of blood tends to gravitate to the legs and the phenomenon can be regarded as the head losing blood to the feet.

This draining of the blood from the head takes time. The graphs in figure 1 illustrate the limits of tolerance of acceleration—the greater the acceleration the less the time that the pilot can retain his sight.

Many measures have been taken to reduce the effect of centrifugal force on the pilot; much may be done by posture and seating; if the pilot's attitude is crouched with his legs raised, the distance through

which the heart has to raise the blood to his head can be reduced and the loss of it to his feet is again less if the feet are high. Another method of lessening the effect of this force which may be mentioned is to place the pilot in the prone position. The heart and head are then nearly at the same height and a man in this position can withstand some $10g$, but this posture is a very fatiguing and inconvenient one for the control of an aircraft, though it is reminiscent of the very earliest airplanes in which the pilot frequently lay prone. The effect of posture on blacking-out is shown diagrammatically in figure 2.



EFFECT ON POSTURE ON BLACKING OUT

FIGURE 2.—Effect of posture on the tolerance of acceleration. (Data from Ruff.)

The engineer has produced machines that are so strong and maneuverable that they can subject the pilot to forces beyond his tolerance and the useful limit in design for maneuverability at high speed changes from being an engineering limit to being a human limit. It would be useless for the aircraft designer to produce an airplane so strong and maneuverable that it could turn with a centrifugal acceleration of $20g$ because the pilot would not be conscious to control it under these conditions; the ability to out-turn the enemy has an important tactical advantage in dog fighting, but to achieve this it is now necessary to look to the man rather than the machine. Figure 3 illustrates how the human limit makes it impos-

sible for a fast airplane to follow a slow one in a tight turn; both pilots are subjected to $5g$.

The most important stress, however, to which man is subjected in aircraft is that resulting from the thinness of the air at great altitudes. The air pressure at ground level is 14.7 lb./sq. in. It has fallen to one-half at 18,000 feet and to only one-fifth, about $2\frac{3}{4}$ lb./sq. in., at 40,000 feet. The effects of altitude on man are those resulting from the lowered atmospheric pressure.

The disabilities which a man suffers at lowered pressure first came into prominence on the surface of the earth as "mountain sickness."

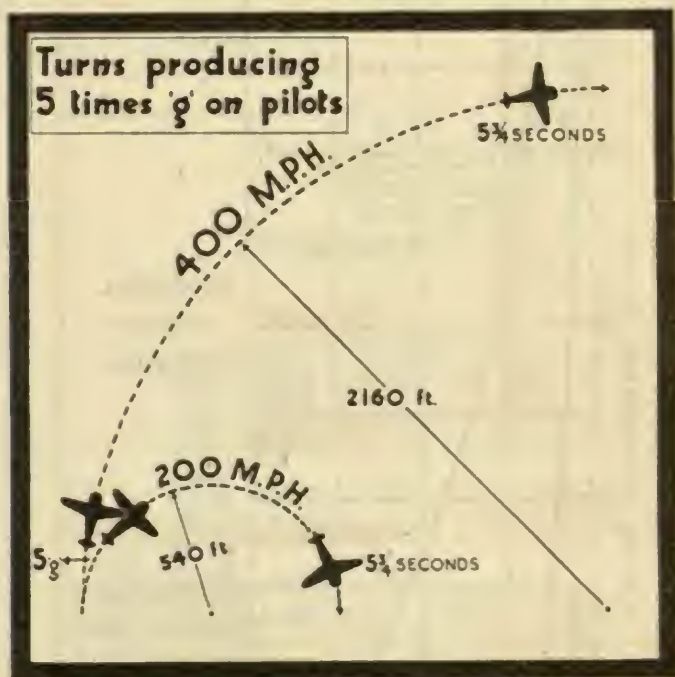


FIGURE 3.—Showing how human tolerance of acceleration makes it impossible for a fast airplane to follow a slow one in a tight turn.

Later the term "balloon sickness" was given to the troubles experienced in high balloon ascents at the beginning of the last century; long before airplanes had become practical flying machines, the problems of high altitudes had been encountered because early balloon ascents carried the balloonists to heights at which the air would hardly support life and at that time their knowledge of how to overcome this was lacking.

Plate 2, figure 2, shows the first successful flight when Montgolfier's balloon ascended from Versailles in 1783 carrying a sheep, a duck, and a cock. After the safe return of these animals to earth, Montgolfier

himself went up some hundreds of feet. Two years later the French scientist Charles reached a height of 13,000 feet with a hydrogen balloon.

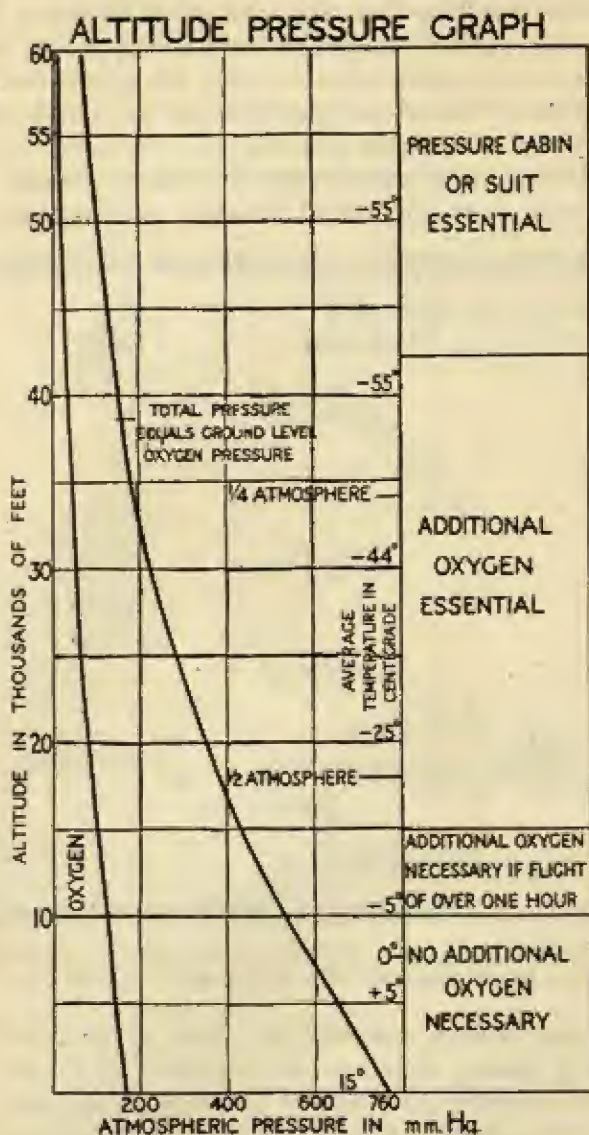


FIGURE 4.—Relationship between altitude and atmospheric pressure. (I. C. A. N. scale.)

Figure 5 shows the upward progress of man's exploration of the air.

It is necessary to emphasize the difference between rapid ascent from ground level, as in an airplane, and slow ascent in climbing

mountains. In the latter case, weeks are spent at 15,000–18,000 feet to become acclimatized to the thin air. Great changes occur throughout the climber's bodily processes which enable him to live at altitudes which are fatal to a "sea level" man. Acclimatization is soon lost on return to ground level, so it is not possible to make much use of this in flying.

Climbers have reached 28,000 feet on Mount Everest, but in contrast to this the first serious high-altitude accident occurred in 1875 when Tissandier with two companions went up in the hydrogen bal-

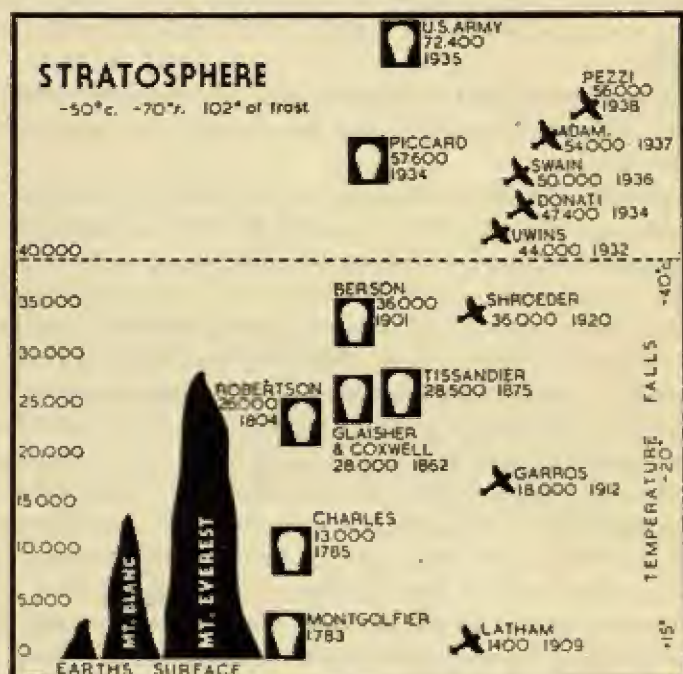


FIGURE 5.—Balloon and aircraft altitude records. (Heights to the nearest 100 feet.)

loon *Zenith*. The balloon ascended to about 26,000 feet and the occupants became unconscious. They became conscious again when the balloon descended to 20,000 feet but then threw out ballast and the balloon rapidly ascended to about 28,000 feet. All became unconscious and when Tissandier regained consciousness the balloon was at about 19,000 feet, descending rapidly, but his two companions were dead. This accident focused a great deal of attention on the physiological problems of altitude, and to investigate these Paul Bert constructed a steel chamber from which the air could be removed by a pump to simulate altitude conditions at ground level. Since then a great deal of research has been carried out in such decompression

chambers, both on mountains and in aircraft, on the nature of altitude sickness and the ways of overcoming it.

Plate 3, figure 1 shows a modern decompression chamber at an R. A. F. Medical Service research unit. In this a man can be taken to a pressure equal to that at 30,000 feet in less than a minute, and it is capable of producing pressures down to a small fraction of a pound to the square inch.

Plate 3, figure 2 shows a small type of decompression chamber of which many are in service, which will take six men to any altitude required so that they can become familiar with their breathing apparatus and the disasters that may befall them if they do not use it correctly.

For life, man needs food, water, and air. He can live without food for weeks, without water for days, but without air he can survive only a few minutes.

At increasing altitudes, although the proportion of oxygen in the air remains one-fifth, the density of the mixture becomes less and a certain pressure of oxygen is essential for living cells to function normally. At an altitude of 42,000 feet if the lungs are filled with air, they contain less than one-sixth of the normal quantity of oxygen and this is insufficient to support life. Much of the Battle of Britain was carried out in an atmosphere in which a pilot unassisted with breathing apparatus would be dead in a few minutes. However, long before this height is reached oxygen lack makes its presence felt in the impaired intelligence and mental performance of the pilot. As oxygen want comes on, judgment is lost, gross errors are made, intelligence fails, muscular control is lost and this is followed by unconsciousness. Moreover, oxygen want is very insidious because the sufferer is often almost unaware of it. At 20,000 feet a man without oxygen may do irrational things; oxygen want resembles drunkenness both in its symptoms and in that the sufferer is confident that he is normal and much resents any suggestion to the contrary.

It would clearly be dangerous to send an aircraft up to 25,000 feet unless it was ensured that the crew were protected from oxygen want. Much research on the practical protection of flying personnel from the effects of altitude has been carried out by the R. A. F., particularly by the Medical Branch which directs research in this very important side of the pilot's welfare. The importance of this is emphasized by the following story of a recent incident which occurred over Germany. A pilot's breathing apparatus became disconnected and the pilot thereupon told the crew that he was going to land. He put down his wheels and tried to land on a cloudbank at about 18,000 feet. He then told the crew over his intercommunication system that they were below ground level and he was going to get out, whereupon the navi-

gator, realizing what had happened, was in time to stop him from climbing out of the machine, take over the controls and reconnect the pilot's breathing apparatus. It is easy to see that such an incident might not always have a happy ending. The effects of oxygen want may often be extremely amusing but clearly there is no place for such events in the dangerous and difficult work of high-altitude flying.

There are two ways in which altitude effects can be overcome. The first is to increase the amount of oxygen in the air which the pilot breathes by mixing oxygen from gas cylinders with it, thus giving the pilot a mixture rich in oxygen or even pure oxygen to breathe. In this way when the pressure is one-quarter of an atmosphere at 33,000 feet if his lungs are filled with pure oxygen he will not suffer from any symptoms of oxygen lack. To this end the pilot always wears an oxygen mask, which also carries a microphone for his communication with the crew or ground.

The second alternative is to increase the amount of oxygen in the pilot's lungs by compressing the air in them. In an engine the loss of power from oxygen lack is overcome by compressing the thin air with a supercharger, but it is not possible to supercharge the lungs so easily as the pressures required would burst them. The pilot must therefore be completely surrounded by air at increased pressure. This can be done either with a pressure suit something like a diving dress or, if the cabin is sealed and made strong enough for it to withstand a raised air pressure, produced by a pump attached to the engine. The air around the pilot can then be kept at 14 lb./sq. in. and the atmosphere he breathes can be exactly like that at ground level. However, it is clear that for military use such a pressure cabin is very vulnerable, though for civil use it is the ideal method in high flying because the passenger is not inconvenienced by a mask on his face and need not be aware, by any change in the air pressure, that he has left the ground. Some pressure cabins are in use in civil airlines in America. The pressure cabin has other advantages over the oxygen mask besides preventing lack of oxygen. At heights up to 36,000 feet a man can avoid oxygen lack by breathing pure oxygen, but above 44,000 feet even breathing pure oxygen he would become unconscious. Moreover the vapor pressure of blood equals the atmospheric pressure at 63,000 feet so if a man could reach this pressure his blood would boil and his lungs be filled with steam. At heights above 40,000 feet it becomes necessary not only to breathe pure oxygen but also to increase the pressure acting on man. Plate 2, figure 1 shows the machine and pressure suit in which Flight Lieutenant Adam broke the world's altitude record by reaching 54,000 feet in 1937. The suit was blown up to some $2\frac{1}{2}$ lb./sq. in. pressure and filled with pure oxygen. In it man could survive even in a vacuum.

Thus the effects of oxygen want can be completely overcome up to altitudes of some 8 miles by breathing pure oxygen and this is done in military aircraft of all nations. Above this height pressure must be applied in addition. In the altitude-record balloon ascents by Professor Piccard and by the United States Army, closed gondolas at raised pressure were used.

Figure 6 illustrates the time elapsing between cutting off the oxygen supply to a man and his becoming unconscious at various heights. From this it will be realized how quickly a pilot must act should his oxygen supply fail at high altitudes.

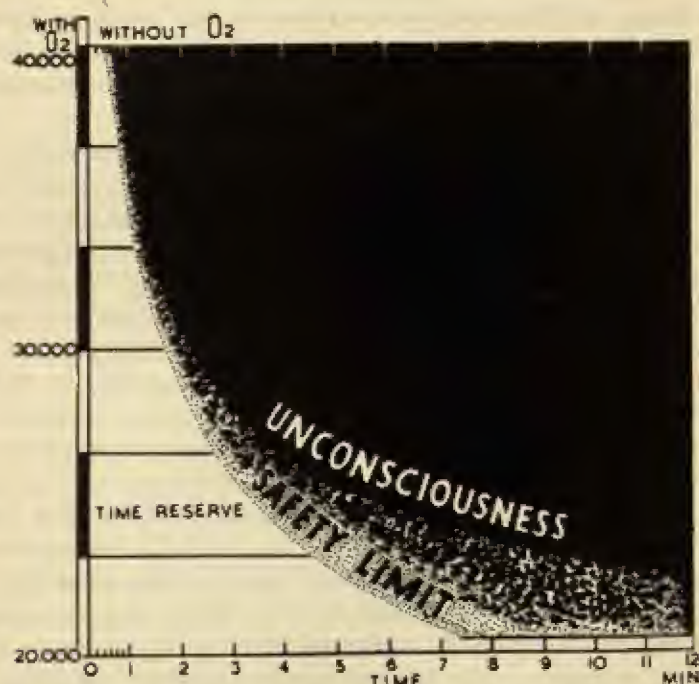


FIGURE 6.—Time between changing from breathing oxygen to breathing air and the occurrence of unconsciousness. (After Ruff.)

The physiological abnormalities at altitude are not entirely solved by breathing oxygen as there are effects on the body at low pressure in addition to oxygen lack. At ground level the air pressure drives nitrogen into the blood which dissolves in appreciable quantity. If now the pressure on the man is rapidly reduced before this nitrogen can escape, it will form bubbles in his blood vessels and stop the circulation. The possibility that something of the sort might occur in animals at low pressures was envisaged by Robert Boyle in 1670 who placed a viper under a bell-jar and pumped out the air; when the pressure was reduced he saw a bubble within the eye of the viper.

Bubbles forming in the body fluids have long been a difficulty in deep diving where men have been subjected to much increased pressures of air. The body fluids then dissolve a large quantity of nitrogen and if the diver comes to the surface too rapidly it cannot escape from his lungs in time to prevent bubbles forming and he gets decompression sickness or "bends" (caisson disease, compressed-air illness), with severe pain, cramps, occasionally unconsciousness and even death. A diver can get severe bends coming up from a depth where the pressure is 4 atmospheres to the surface where it is only 1 atmosphere, but fortunately an airman does not get into such serious difficulties if he goes from ground-level to one-quarter ground-level pressure at 33,000 feet. Bends as they occur in the air are rarely experienced at altitudes below 25,000 feet. They come on slowly and are rarely of a serious nature. Unconsciousness can result if the warning symptoms of pain in the joints are neglected. The pains are cured almost instantaneously if descent is made to about 25,000 feet where the air pressure compresses the nitrogen bubbles sufficiently to drive them back into solution in the blood.

Much research has been carried out on men in decompression chambers to find ways of alleviating these effects. One method is to breathe pure oxygen before ascent, so replacing the nitrogen in the blood with oxygen. The oxygen is then used up in the tissues before it can form bubbles. This method has long been used to displace nitrogen from the blood in diving.

There are other disturbances to man with rapid changes of altitude resulting from the change in air pressure. Behind the ear drum is a cavity filled with air which communicates through a small canal with the throat and it is necessary for air to leave and enter it with ascent and descent lest the ear drum be collapsed. The canal to the throat will normally open on swallowing and in a dive a pilot clears his ears almost unconsciously, but should he fail to do so or have severe catarrh, he may damage his ear drums. Enclosed gas elsewhere in the body, as in the sinuses surrounding the nose, has to equalize its pressure as the altitude changes or severe pain may result. Again on ascent the gas normally present in the intestines expands to a larger and larger volume as the outside pressure falls when climbing but this is rarely a serious problem.

Thus the human safety limit in height is some 10,000–16,000 feet breathing air and 40,000–42,000 feet breathing oxygen; heights much in excess of the latter are only achieved by enclosing the pilot in an artificial atmosphere.

But it is clear that starting with fit pilots on the ground much must be done to keep them efficient in the air and the efficiency of the man may often be of even greater importance than that of the machine.

We know that in the Battle of Britain quality in men and machines overcame weight of numbers and although always greatly outnumbered, the R. A. F. by efficiency and courage were able to rout the Luftwaffe. To maintain that efficiency in the air and at high altitudes is no mean problem. That it is done is the result of scientific research during the last 70 years into life at great altitudes and the successful application of what has been discovered to the particular problems of the pilot. I should like this lecture to be considered a tribute to all those scientists from Paul Bert onward and to many officers of the R. A. F. who have contributed so much to the solution of high-altitude flying and in particular to those medical officers who have lost their lives in this war in flying experiments.



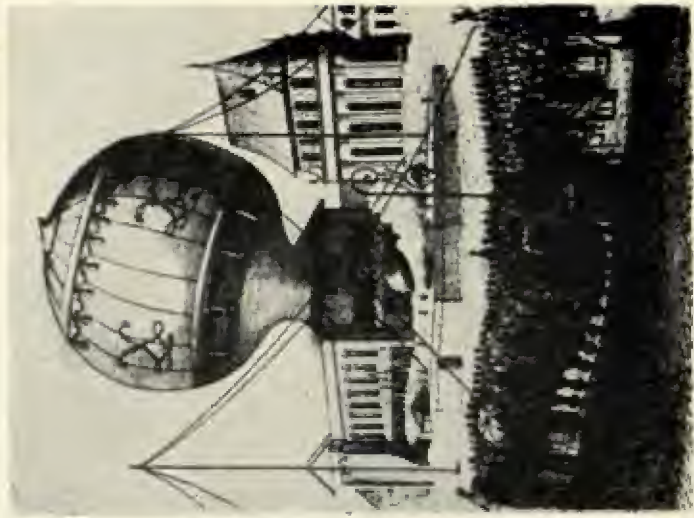
1. MAN DURING STRAIGHT AND LEVEL FLIGHT.



2. IN A TIGHT TURN PRODUCING ACCELERATION OF $4\frac{1}{2}g$ 15 SECONDS LATER.



1. FLIGHT LIEUTENANT ADAM WEARING THE PRESSURE SUIT IN WHICH HE
BROKE THE WORLD'S ALTITUDE RECORD IN 1937.
Copyright "The Aeroplane" (England). Reproduced by permission of Temple Press Ltd.



2. MONTGOLFIER'S BALLOON ASCENT FROM
VERSAILLES.
(From an old print.)



1. INTERIOR OF AN R. A. F. DECOMPRESSION CHAMBER LOOKING IN FROM ONE OF THE GLASS PORTHOLES.



2. R. A. F. MOBILE DECOMPRESSION CHAMBER.

This is self-contained with an engine-driven pump, oxygen cylinders, and controls operated from the left-hand cab.

TRANS-ARCTIC AVIATION¹

By ELMER PLISCHKE, LIEUTENANT (J. G.), U. S. N. R.

Frequently it is wise and profitable to spend a few moments in speculation on the potentialities of the future. Many improvements are bound to be occasioned by the necessities of the war, not the least of which is the impressive development in aviation. The technological advancements being perfected for war purposes today doubtless will revolutionize commercial aviation after the termination of hostilities. One of the most logical results is the linking of the continents by a network of air routes traversing the Arctic Basin.

Belief in the physical practicability and in the commercial value of trans-Arctic aviation was first manifested about the time of World War I, and in 1919, W. Brun, a German, proposed the organizing of regular flights from the European capitals via Archangel, the Arctic Basin, and Nome or Unalaska, to either Yokohama, Vancouver, or San Francisco. A few years later, in 1923, Maj. Gen. Sir Sefton Brancker, Director of Civil Aviation for Great Britain, enthusiastically declared in a speech at Sheffield that the carrying of mails from England to Japan by way of the Arctic was a probability of the next 10 years. In connection with the preparations for the flight of the dirigible *Shenandoah* to explore the polar "white spot" between Alaska and the North Pole, Rear Admiral William A. Moffett, Chief of the Bureau of Aeronautics of the United States Navy, stated in 1924 that polar air routes connecting England, Japan, Alaska, and Siberia are possibilities of the near future.

Many writers have since expressed their belief in the future of trans-Arctic flying. But perhaps the most vocal of these exponents is the polar explorer and publicist, Vilhjalmur Stefansson, who has been pointing out the positional importance of the Arctic Basin for the past 20 years. On a map which has the North Pole as its center, he explains, the Arctic constitutes a small hub from which the land masses radiate like spokes of a great wheel, thus lying in the central part of a circular region enclosed for the most part by northerly extensions of rich and densely populated modern countries. By the logic of its position, it

¹ Reprinted by permission from *Economic Geography*, vol. 19, No. 3, July 1943. All assertions and opinions are purely those of the author and are in no wise to be construed as reflecting the views of the Navy Department.

TRANS-ARCTIC FLYING DISTANCES

The distances of air travel between many major locations throughout the world, especially within the Northern Hemisphere, can be markedly reduced if trans-Arctic air routes are pursued, as illustrated by the accompanying tables.

The distance between New York and Moscow is about 1,000 miles shorter via the Arctic Basin and its peripheral landed areas. From Seattle to Calcutta the distance is almost 5,000 miles shorter, while over 6,000 miles is saved along the polar route from London to Tokyo. Similarly, the distances between New York and Tokyo and between San Francisco and either Moscow or London is thousands of miles shorter via the Arctic.

Further implications of polar air geography are of striking interest. From North Cape (Norway) it is just as far to Washington, D. C., as it is to Detroit, Chicago, Des Moines, or Seattle. Chicago is as close to every capital of Europe as it is to Buenos Aires. Milwaukee, Detroit, and other great midwestern war production centers, are closer to Russia by air than are any of the great seaports of the United States.

TABLE 2.—*Trans-Arctic long-distance flying*

From—	To—	Miles	Hours	Minutes
Berlin.....	Tokyo.....	4,900	16	20
Chicago.....	Moscow.....	5,050	16	50
Detroit.....	Murmansk.....	4,150	13	50
London.....	Tokyo.....	5,500	18	20
Los Angeles.....	Murmansk.....	5,845	19	29
Minneapolis.....	Bombay.....	8,000	26	40
Montreal.....	Igarka.....	4,650	15	30
New York.....	Berlin.....	4,000	13	20
Do.....	Chungking.....	7,600	25	20
Do.....	London.....	3,475	11	35
Do.....	Moscow.....	4,600	15	20
Do.....	Murmansk.....	4,000	13	20
Do.....	Tokyo.....	5,900	19	40
San Francisco.....	Bergen.....	4,750	15	50
Do.....	London.....	5,150	17	10
Do.....	Moscow.....	5,650	18	50
Do.....	Tokyo.....	4,500	15	-----
Seattle.....	Calcutta.....	7,225	24	50

The saving in mileage and time by following these Arctic airlines is considerable. At 300 miles per hour—which is by no means an impossible rate of speed in the light of recent increases in flying rates—transports can easily carry their passengers and cargoes between Berlin and Tokyo, Chicago and Moscow, Montreal and Igarka, New York and Berlin or Moscow, and San Francisco and London or Tokyo in less than half the time it takes a crack train to make a nonstop run from New York to San Francisco at 80 miles an hour.

Planes also can bridge the gap between New York and Chungking, Minneapolis and Bombay, or New York and Tokyo in considerably less time than the special express train will require to cross our country. Finally, at 300 miles per hour, wherever one may happen to be, no spot on the once wide globe is farther away than 42 flying hours.

Unbeknown to most of us, much already has been done to utilize and develop these northern routes. Returning from his globe-girdling tour some months ago, Wendell Willkie flew from China to the United States, not by way of Australia and Honolulu as might very well be expected, but rather via Nome (Alaska) and Edmonton (Alberta). Strict censorship veils the full extent of the action taken in promoting polar aviation, but we are informed that millions of dollars have been spent, and that Arctic routes are constantly being flown. Preparations also are being made by the Government of the United States to sponsor and protect American interests in postwar aviation.

ARCTIC FLYING CONDITIONS

But it is frequently believed that flying conditions in the Arctic will prevent the establishment of dependable commercial traffic. True, flying conditions in the polar regions are necessarily different in many respects from what they are in more temperate climates. Nevertheless, upon closer analysis it appears that most of the difficulties can be surmounted.

It is stated that the most ardent exponents of transpolar aviation consider average flying conditions over the Arctic throughout the year to be better than they are over the North Atlantic, while the most pessimistic writers consider them probably worse, but conquerable. Stefansson, one of the most optimistic of the publicists, notes that scientists were virtually unanimous by 1930 in agreeing that Arctic flying in Alaska, to be more specific, is as safe as it is in Michigan. This, he alleges, is suggested by Pan American Airways reports to the effect that its flyers generally are as well satisfied with their work in Alaska as in Brazil, that over half the pilots on its Alaskan lines prefer January to July, and that, assuming like equipment and ground service, schedules can be maintained through the midwinter period with an average regularity at least as good as that in the northeastern part of the United States.

Temperature seems to be no more of a flying problem in the Arctic than elsewhere. The reason for this is that planes now fly in temperatures just as severe in Temperate and Torrid Zones while they are at high altitudes following their established air routes. As a matter of fact, today effective combat is waged at much greater heights than was believed possible a few years ago. It is reported in the press that fighter planes now are regularly flying in the low

temperatures experienced at altitudes of 30,000 and 40,000 feet or more, and our larger bombers repeatedly encounter temperatures of 25° to 50° F. below zero without considering it a limitation upon their effectiveness.

In the polar regions there is less diurnal change and less temperature variation than elsewhere. Flying temperature is said to be hazardous neither at extreme heat nor at extreme cold, but at an intermediate range in the vicinity of, and especially just below, the freezing point of fresh water, for it is at this temperature that ice forms on the aircraft and weighs it down. Such freezing is not very troublesome in the Tropics except at high altitudes, and even in the polar regions icing is less of a problem than it is in the northern half of the Temperate Zone—where air lines function regularly according to well-integrated schedules.

Various technological improvements were devised to prevent, or at least substantially reduce, the formation of an ice covering on the wings and fuselage of a plane. This is evidenced by the fact that fighter planes are constantly flying through the lower aerial zones saturated with the moisture which causes the icing, and perhaps especially by the fact that effective aerial warfare is being waged in the foggy and moist atmosphere surrounding the Aleutian Islands and the shipping lanes to Murmansk. Planes also are used for reconnaissance purposes at low altitudes by the Soviets along the Northern Sea Route between our northwestern coasts and the Arctic ports of the Soviets.

A number of polar explorers, including Richard E. Byrd, who has flown in both polar regions, contend that polar flying is practicable only at certain times of the year. The spring months, from March to May, are said to be best suited for aviation in the Arctic, because the snow is still hard and smooth and there is less fog than there is at other times of the year. But this objection seems to be concerned more with landing and taking off than with flying itself, and it certainly does not apply to long-range nonstop flying.

At first glance it would seem that a genuine problem of polar aviation is the prevention of oil from freezing and the difficulty of starting the motors in severe temperatures. But oil will not freeze while the motor is operating and can be preheated before the motor is started. The problem of starting the motor in sub-zero temperatures was solved some 15 years ago, when it was learned that fireproof hoods or special coverings can be used to keep motors warm when a landing is made, as well as for starting a cold engine. A tube leads from this hood down to a heater which conducts heat up to the motor, or powerful warming lamps may be fitted to the motor. In this manner the motor can be preheated to any temperature, and multi-

motored planes are fitted with so-called "communicators," rendering it possible to warm one motor by the action of another.

The greatest obstacle to Arctic flying is poor visibility due to low-lying clouds and fog. In the 46-hour flight of the *Norge* from King's Bay (Spitsbergen) via the North Pole to the northern coast in Alaska, 16 hours—or about 35 percent of the time—were spent in fog. Such fog is a common occurrence in the polar regions, especially where warm air, inflowing from lower latitudes over open water, meets cold air over pack ice or glacier-covered land, as is the case in Arctic areas during the summer months. Almost all floating ice is said to be accompanied by fog, but when the ice is firmly attached to land, as it is in the wintertime, the atmosphere is relatively free from fog. Fog therefore seems to be a seasonal problem, but it does appear in winter in the region of the Bering Sea and the Aleutian Islands, where the warm Japan Current enters the Arctic, and along the southern edge of the Arctic pack north of Europe where the warm Gulf Stream encounters it.

But fog in the Arctic is less dense and lower lying than it is elsewhere. Since it seldom rises to a height of over 3,000 feet, planes can fly over it with little difficulty. It is also thin so that planes can cruise at low altitudes, and because there are no obstacles like mountains, except over landed areas such as Greenland, Spitsbergen, and parts of Alaska and Siberia, the Arctic pilot can see through the fog and still retain sufficient horizontal vision. When Arctic areas are properly mapped and a greater number of radio stations are in operation to give reliable bearings to the polar flyer at all points along his route, it will no longer be necessary to fly by rivers and other landmarks, as is now the case.

Opinion seems to be somewhat divided as to whether dependable regular and emergency landing facilities are available in the polar regions. On the one hand, it is believed that Arctic waters provide dangerous landing fields, for, although the water's surface often appears clear from above, it may be filled with small lumps of partially submerged ice which can easily wreck a plane as it tries to land. Because of the movement of Arctic ice, moreover, openings fail to remain open, so that a plane, as it alights upon the water, may rapidly be hemmed in and crushed by the ice. In the summer months driftwood also endangers an attempt to land upon the surface of the water.

As far as landing upon the pack ice is concerned, it is estimated that perhaps 90 percent of this surface is too rough to be used successfully, although there occasionally are some stretches of level ice upon which a plane may safely alight. But even if the landing is achieved without mishap, it frequently is more hazardous to take

off from such surfaces, especially because high speeds are now necessary.

Stefansson seems to be somewhat more optimistic concerning natural Arctic landing facilities. He claims that the Arctic and the northern third of the Temperate Zone excel the rest of the world in number and quality of emergency landing fields, noting that there are millions of lakes which provide suitable spots for landing with pontoons or skis. These many landing fields, he continues, have given polar flying a greater safety percentage than exists in other zones, even in the Tropics. On the Arctic pack ice there are few sections where good landing fields are more than 20 miles apart, there generally being a choice of two or more within the gliding range of a plane if its motors stop at an altitude of a mile or more. In support of this contention, Stefansson asserts that during a single decade at least 54 such emergency descents were made in every sort of weather, outstanding among which was the third descent of George H. Wilkins, undertaken at night in a blizzard when he alighted upon the ice pack 100 miles off the northern tip of Alaska. No life was lost in any of these descents, while the distance covered amounted to over 90,000 miles. Again, no lives were sacrificed in the search for the Russian flyer Levanevsky in 1937, in which some 50,000 miles were flown.

Contrary points of view are held concerning the suitability of the ice cap of Greenland as a polar landing field. One group of writers contends that, despite a prolonged search undertaken by the Danish Government, there is no known natural landing field in all Greenland. The ice cap is described as an undulating plain, difficult of access because it is girdled by a ring of mountains which must be flown over and which usually constitute one of the greatest hazards of aviation everywhere. In addition, there are steep, jagged fissures into which ice pours through the mountains as glaciers. Unless the plane is especially equipped for a perilous overland journey, an emergency landing is apt to leave the hapless party exposed to the bitter elements on the ice cap. Recently two daring aerial rescues of 15 stranded American Army flyers were disclosed in the press, but both accounts leave no doubt whatever as to the dangers encountered.

The opposite point of view argues that Greenland's ice cap is the world's largest and finest natural landing field. It is said to form a continuous and nearly perfect emergency airdrome 1,500 miles long and up to 600 miles wide. Local gales along its coasts probably can be offset by selecting nonwindy flying lanes. The use of the southern part of the island as a route by which military planes are ferried across the Atlantic seems to justify this opinion, at least in part.

The majority of these hazards attending polar flying may rapidly be eliminated through the perfection of technological and other im-

provements. Since most of the obstacles are mechanical, they apply to flying elsewhere as well. Once they are overcome, the Arctic will possess the inestimable advantage of shorter distances. Even the problem of fog can be at least partially overcome by the development of suitable radio facilities, supplemented with appropriate polar mapping, which can itself be done by planes.

As long-distance flying increases in both extent and security, there is little to gainsay the future of trans-Arctic aviation. Many aerial feats, which were believed to be visionary but a short time before the outbreak of World War II, are already looked upon as commonplace. Who can predict what will be possible within the next decade or two by a fleet of superplanes, such as the famous 82-ton B-19, with a wingspread greater than the height of a 17-story building, with fuel tanks containing 11,000 gallons of gasoline, and with a range of almost 10,000 miles—which can carry it on a nonstop flight from San Francisco via New York to London and back to New York, or from Minneapolis to Bombay. Current improvements in design and construction appear to herald fleets of mammoth 100-ton cargo and passenger planes possessing a size and flying range never dreamed of a few years ago.

TERRITORIAL JURISDICTION

It is such aerial potentialities as these that impel writers and governments to turn anxious eyes toward the appropriable landed areas that remain in the Far North. The successful establishment of trans-polar aerial communication will necessitate the construction of flying lanes, landing bases, and radio and meteorological stations. Since the ice in the Arctic is in constant motion and cannot be relied upon for the erection of permanent facilities, polar landed territory will become of supreme importance. The establishment of flying auxiliaries by the nationals of a state unquestionably will rouse their government to acquire the territorial jurisdiction necessary to preserve and maintain these facilities properly. The race for polar territory therefore promises to be very close at hand.

Under the recognized principles of international law, unpossessed territory (*terra nullius*) in the Arctic, as well as elsewhere, can be acquired juridically only by effective occupation or by prescription. By occupation is meant the intention to possess the territory in question and both the administration of state acts and the exercise of police power in sufficient strength to protect life and property and render exceptional a breach of the laws of the occupying state. Prescription means the exercise of state authority over such a length of time as is necessary under the influence of historical development to create the general conviction that the present situation is in conformity with the international order. Contrary to popular belief,

discovery does not accord a perfect title to new territory, but merely affords an inchoate title which must be substantiated by effective occupation within a reasonable length of time.

A recent Soviet school of thought has proposed a new theory to govern the acquisition of polar territory in the Arctic. It is known as the sector principle, according to which a subjacent polar state automatically possesses all territory, discovered and undiscovered, lying to the north of its mainland and within the area bounded by an extension of its longitudinal extremities to the Pole. Thus, the Arctic, like a huge pie, is sliced into a small number of sectors, one accruing to each of the following peripheral states: Norway (Spitsbergen), Finland, the Soviet Union, the United States (Alaska), Canada, and Denmark (Greenland and Iceland). But this sector principle enjoys no validity under international law and has been recognized only in the municipal law of the Soviet Union. The other five Arctic states have either refrained from committing themselves upon the principle, denied its validity by implication, or openly rejected it in their state papers. Even the Soviet Government has not made any attempt to rely upon polar sectorism in its international affairs.

What, then, is the juridical status of the territory in the Arctic which is so important for the development of postwar air transport?

In some instances the reply is relatively simple. Thus, the entire island of Greenland belongs to Denmark, as acknowledged in a series of declarations made by the United States, Great Britain, France, and Japan, 1916-1920, and by the Eastern Greenland Arbitration of 1933 between Denmark and Norway which recognized the Eirik Raudes Land area as belonging to the former. But, according to the recent announcements by President Franklin Delano Roosevelt and Secretary of State Cordell Hull, the island lies in the Western Hemisphere and therefore comes under the aegis of the Monroe Doctrine, which prohibits non-American states from acquiring the island. By and large, the same is true of Iceland, except that it enjoys an unusual autonomous constitutional position with relation to the Danish Crown.

Spitsbergen, together with Bear Island, was recognized as Norwegian territory by the Spitsbergen Treaty of February 9, 1920, following at least a quarter century of dispute involving Germany, Great Britain, Norway, Russia, Sweden, and the United States. Norway also possesses Jan Mayen Island, having formally announced the extension of its jurisdiction over the island on May 8, 1929.

Since 1920 the Soviets have taken a more aggressive course of action in the Arctic than has any other state. Despite the decree of April 15, 1926, incorporating the sector principle into its municipal law,

the Government of the U. S. S. R. nevertheless has adopted an active policy of effective occupation, settlement, and administration for the islands to the north of its mainland. Thus, a number of important institutions were organized, especially the All-Union Arctic Institute for the scientific study of the Arctic, and the Central Administration of the Northern Sea Route (Glavsevmorput) which exercises economic, administrative, and judicial supervision in the Arctic islands. A scientific method of exploration, annexation, and colonization is being pursued. In addition, some 200 Arctic scientific radio and meteorological stations were erected, of which about 75 are located on the islands. Finally, with the assistance of an elaborate state-owned system of icebreaker and aerial reconnaissance service, the difficult Northern Sea Route, which parallels the northern shores of the Soviet mainland, is regularly traversed by a fleet of public cargo vessels, the annual shipping amounting to approximately 500,000 tons prior to the outbreak of hostilities between Germany and the U. S. S. R.

In view of this active display of jurisdictional action on the part of the Soviet Government, no pretensions have been raised by other states to territory lying within the limits of the Soviet sectoral decree, except those entertained by Canada and Norway with respect to Wrangel Island and Franz Josef Land respectively. But the U. S. S. R. has in any case established continuous settlements on Wrangel Island since 1926 and has been sending annual parties to Franz Josef Land to supply and maintain a network of permanent stations established there.

No known territory lies to the north of Alaska, and for some years the United States has raised no serious pretensions to any Arctic possessions. But considerable interest was at one time centered in Wrangel Island and a number of smaller islands lying to the north of the eastern tip of Siberia, including especially Herald, Jeannette, Henrietta, and Bennett Islands. To the north of Canada, the American Government displayed some interest in Ellesmere Island and at least on one occasion refrained from applying to the Canadian Government for licenses to fly over the Sverdrup Islands (Axel Heiberg, Amund Ringnes, Ellef Ringnes, and a number of surrounding smaller islands), which is required under Canadian law and which would have acknowledged our recognition of Canadian jurisdiction over these islands. As far as Greenland is concerned, the American Government always has been actively interested. Upon the insistence of Secretary of State William H. Seward, a valuable report was prepared on the island as early as the 1860's with a view to possible annexation; in 1910 there was some discussion of the cession of the island by Denmark to the United States in exchange for

the Philippine Islands, which in turn were to be ceded by the Danish Government to Germany in return for northern Schleswig; 6 years later the American Government agreed not to object to an extension of Danish jurisdiction over the entire island; and, finally, within the last few years Greenland was acknowledged to constitute a part of the Western Hemisphere and is therefore subject to our special interests under the Monroe Doctrine.

The Dominion of Canada claims all the known islands lying to the north of her mainland. This pretension has not always been respected, as indicated, so that for the past 15 years a serious effort has been made to subject the entire island empire—as embraced within the jurisdiction of the Northwest Territories and Yukon Branch of the Canadian Department of Interior—to effective state administration. This is promoted particularly by the establishment of Royal Canadian Mounted Police posts on the fringe of the islands area, by extensive police patrols centered about these posts, by an earnest attempt to enforce the Canadian legal system in the vast region, and by the exploits of the Annual Arctic Patrols, which man and supply the posts. The Dominion, like the Soviet Union, therefore is seeking to establish an absolute juridical title to the polar territory adjacent to its mainland.

In this manner, Denmark, Norway, the U. S. S. R., and the Dominion of Canada possess, or claim to possess, all known territory within the Arctic Basin. Moreover, under international law, states enjoy all rights of jurisdiction over the air space superjacent to their domains, and the air routes which traverse the Arctic will cross the territory of these four states. If their pretensions to the territory are acknowledged as valid under law, they will be in a position to control the major share of the trans-Arctic air lanes. On the other hand, if their claims are controverted, serious jurisdictional disputes may arise, as was the case with Spitsbergen, Wrangel Island, and eastern Greenland.

To avert such controversies, it would seem advisable for the post-war conference of states to establish a practicable solution for the international control of the matter. The problem of territorial jurisdiction should be solved in advance by an international understanding through the establishment of specific principles of law, as was effected at the Berlin Conference of 1884-1885, when the majority of the Powers recognized the principle of effective occupation as essential for the juridical acquisition of African coastal lands. This is a matter of first magnitude and should be resolved before a host of jealously regarded vested interests are created. At present, potential disputes are largely legal in nature and therefore are amenable to justiciable solution. But if proprietary interests with exten-

sive financial backing are permitted to develop, the matter of resolution will be infinitely more difficult. Experience has shown beyond a shadow of doubt that disputes involving important economic and political interests are far more difficult to solve than are those of a purely juridical nature.

A series of multilateral air law agreements also will have to be decided upon, and it might be profitable if an international body were established to administer such problems as reconnaissance, the surveying and laying out of transport lanes, the allocation of franchises, the adoption and enforcement of administrative air regulations, and the like. But these suggestions can readily be agreed upon if the jurisdictional issues are settled.

On a number of occasions it has been proposed that remaining unoccupied polar territory be recognized as belonging to the Society of States (i.e., as *res communis* rather than as territory belonging to no state, *res nullius*). Then no state could legally acquire a valid title to the territory and no title of an individual state would be valid as against the others. Naturally this applies only to island territory, and does not include those islands already consigned to a particular state by international agreement—as was the case with Greenland and Spitsbergen—and those islands which can be considered as appertaining to a state by virtue of prescriptive rights. All remaining Arctic island territory should be internationalized, to be administered either by the League of Nations or its future counterpart, by some special international administrative agency, or by some qualified individual state as a mandate.

OUR PETROLEUM RESOURCES¹

By WALLACE E. PRATT

Standard Oil Company (New Jersey)

As "a nation on wheels" we came long ago to rank petroleum, the source of lubricants and liquid fuels, close to the top of our list of essential commodities. Recently, as a nation at war utilizing petroleum as raw material for indispensable plastics and synthetics, including rubber, and even for the TNT of our bombs and high-explosive shells, we have accorded it a still more important place in our national economy. Barring the conquest of some new, revolutionary form of energy, petroleum must continue to be one of America's paramount necessities.

What, then, of petroleum for the future? We all realize that the petroleum resources of the earth are a waning asset; so far as the needs of mankind are concerned there is no renewal of supply. How large are the reserves available to us and where are they situated?

The following quotation is typical of recent press comment on the subject of our petroleum reserves in the United States: "This nation's proved reserves of petroleum now bulk some twenty billion barrels, a quantity equal to our present peace-time requirements for a period of about 15 years. Over the last three years our discoveries of new reserves have consistently failed to balance our annual consumption." These oversimplified figures, though entirely accurate, lend themselves readily to misinterpretation. Many people conclude from them that 15 years hence we will have no gasoline for our automobiles. They even fear critical shortages of petroleum products for present war needs. The misunderstanding might in some degree be dispelled if the facts were more fully revealed.

The statement quoted leads to the assumption that our 20 billion barrels of proved reserves in the United States constitute our total remaining resources in petroleum. Yet in fact our total resources far exceed our proved reserves. In the first place much petroleum remains to be discovered in the United States. Less than half the total area promising for petroleum has been thoroughly explored. In much of

¹ Reprinted by permission from the *American Scientist*, vol. 32, No. 2, April 1944.

the region already producing, only the upper layers of the petroleum-bearing rocks have been tapped by the wells so far drilled. Underlying the beds from which petroleum is now being withdrawn in many of our great oil fields there remain thousands of feet of rocks, still untouched by the drill, which may very well yield petroleum when they are tested.

Our total past discoveries of petroleum in the United States amount to about 48 billion barrels. We have explored great areas which most of us have agreed were of little promise. Yet our past experience has proved that from 1 to 2 percent of the total area in which we may reasonably hope to find petroleum actually produces when thoroughly tested. If our average experience in the area already thoroughly explored is valid, then thorough exploration of the entire area in the United States in which it is reasonable to expect to find petroleum should yield as much additional petroleum as we have already found.

Moreover, the statement under consideration overlooks the fact that in addition to the 20 billion barrels of liquid petroleum reserves we have also in the United States proved reserves of natural gas equivalent in energy content to about 17 billion barrels of petroleum. Natural gas is really petroleum in another form and with modern technique is readily convertible into liquid fuels, although the cost of conversion is still somewhat higher. We should not overlook our reserves of petroleum in the form of natural gas.

Again the statement ignores the fact that the American petroleum industry, operating abroad over the last 30 years, has developed additional petroleum resources in other countries. The remaining proved reserves in these oil fields easily amount to another 20 billion barrels or more. These reserves in the hands of American nationals in other countries have always been available to the American consuming public in normal times, and they constitute an important supplementary proved reserve of petroleum.

The current discussions of the amount of our petroleum reserves seldom touch on the facts that in the past we have usually recovered only about 40 percent, or less, of the total volume of petroleum originally present in our oil fields, and that, on the basis of this past experience, proved reserves are customarily estimated at about 40 percent of the total volume of petroleum in the natural reservoirs in which the estimates apply. Our estimates of reserves include only the petroleum that we know from experience will flow more or less spontaneously into the wells that are drilled. The sum of our estimates of proved reserves plus the petroleum already discovered in this country, some 48 billion barrels, represents, therefore, a total original volume of about 120 billion barrels. After the estimated volume of our proved reserves has been completely recovered there will still remain underground in

our depleted oil fields some 70 billion barrels of petroleum. With improved methods of secondary recovery much of this additional reserve is certain to be reduced to possession and utilized over the long future.

In summary, then, the total proved reserves of petroleum in the oil fields already discovered by Americans, at home and abroad, are of the order of 40 billion barrels. Associated with these reserves of liquid petroleum there are proved reserves of natural gas, or gaseous petroleum, equivalent in available energy to an additional 17 billion barrels, or more, of petroleum. Thus we have a minimum proved reserve of 57 billion barrels of petroleum in the hands of the American petroleum industry. And after this entire reserve has been exhausted there will remain in the ground in all the oil fields in the United States from which our past supplies have been withdrawn an additional 70 billion barrels or so which we may certainly hope ultimately to reclaim in part by improved methods of recovery.

As to the decline in the rate of discovery of new oil fields in the United States, it should be realized that our normal oil-finding effort has been a war casualty. The failure to discover a larger number of new oil fields is largely due to the fact that finding oil has been sacrificed to other objectives which we have felt were more important to the national welfare in time of war. Crude-oil prices were at low levels when we entered the war. Proved reserves had been increasing, there was little incentive to risk capital in exploration, a hazardous venture at best. In the midst of this depressed situation war broke out and denied to the petroleum industry the critical materials, the manpower, and the price increases that were essential to stimulate exploration. Except for these restrictions "wildcatting" by the thousands of small independent enterprises that constitute the mainstay of our oil-finding industry would have been multiplied and our national discovery rate would certainly have maintained a higher level. Oil finding is an increasingly difficult undertaking in this country at best, but during the recent emergency we have simply failed to sustain normal exploratory activities.

A significant fact which may be deduced from the statement we have quoted is that our ordinary peacetime consumption of petroleum in the United States amounts to 450 gallons per capita annually. Compare this figure with the annual consumption for the average citizens of the rest of the world, which is 15 gallons; or with 80 gallons for the average citizen of the United Kingdom, or 50 gallons for the average Russian. We use 30 times as much petroleum per capita as the rest of the world uses!

Petroleum in the modern world is potential energy. With our machines it is converted into mechanical work. High standards of

living result from a large per capita production of goods. The culture of ancient Greece was founded on the labor of human slaves. Our high standards of living rest largely upon the mechanical work done for us by petroleum. The consumption of petroleum in this country provides us with the work equivalent of more than 4 billion able-bodied men laboring 8 hours a day, 6 days a week, year in and year out! In effect our petroleum provides us with an average of 36 strong, able-bodied slaves for every man, woman, and child in the United States; for the average American family, petroleum does the work of a staff of 144 servants!

This fortunate condition, America's abundant supply of petroleum, is due, we are commonly asked to believe, to the fact that our country has been blessed with unusually rich natural resources of petroleum. This is a mistaken idea and to accept it is to ignore an even more precious heritage with which as a nation we have been blessed.

We have produced more than 60 percent of the petroleum the world has consumed so far. But this does not mean that we possess 60 percent of the world's petroleum. Outside the United States exploration for petroleum has hardly begun. The fact is that most of the really rich petroleum resources of the earth lie outside our national boundaries. In comparison with them the quality of our domestic resources appears rather meager. The areas of first-class promise for petroleum over the earth's surface aggregate some 6 million square miles; of this total, about 15 percent, or less than 1 million square miles, are included within the boundaries of the United States. When the petroleum resources of the earth have finally been fully developed it will probably have been established that less than 15 percent of the total petroleum in the earth's crust lay beneath the surface of the United States.

What we in America have been blessed with is a native genius which, in combination with our political and social concepts, has enabled us to explore for petroleum more effectively and to discover the hidden resources in our country more rapidly than any other people on earth. Our abundance of petroleum has come to us because we dug down into the earth all over the land until we found it. No other nation has made any comparable effort to develop its petroleum resources.

To the task of oil finding, in addition to the method of applied science and a flair for industrial organization, we have brought the spirit of the pioneer. To an ingenuity which enabled us to design and operate the ponderous mechanical equipment required to drill and recover petroleum from wells of unprecedented depth, we have added the frontiersman's characteristic risk-taking instinct. Driven by this instinct, equipped with this machinery, we have gone about

over our country searching for petroleum, setting up hundreds of independent wildcatting enterprises, drilling thousands of exploratory wells every year for a generation. Our geographic frontiers having been subdued, we have searched out a new frontier in the vertical dimension, beneath the surface of the earth. The conquest of this new frontier has brought us our abundance of petroleum and the high living standards that it sustains.

Every nation has this same vertical frontier but no other nation has explored it as we have. Over much of the earth, where the natural obstacles are no more formidable than those we have surmounted, political and social barriers have prevented the effective development of petroleum resources. We, too, might have failed had we not enjoyed our traditional freedoms. Restrictions by the State on the right to drill exploratory wells, State ownership of minerals, State monopoly of rights to explore—any of these restraints would have gravely handicapped the search for petroleum we have carried out in the United States. Even the presence of a landed gentry with unbroken ownership over large areas, in contrast to our widely divided ownership in small tracts, would have seriously retarded our efforts. Our methods could not have been employed successfully in any other than an atmosphere of democratic free enterprise.

If the wells we drill into the earth are successful they usually encounter petroleum in the pores and small voids of marine sedimentary rocks. The petroleum is derived, we believe, from the organic remains of former marine life. Sedimentary rocks are the muds, sands, and oozes that have accumulated on the floors of seas in past geologic ages. The hardening of these materials into rock has taken place slowly under the pressure of the load of later sediments deposited on top of them.

The search for the petroleum resources of the earth, taking account of this theory of origin, should be directed to those regions where in the past marine sediments rich in organic matter have been laid down in great depth and volume. Marine life, the source of organic matter, abounds in surface waters near shore, and marine sediments also are deposited in greatest volume near shore, where the streams from the adjacent land drop their load of mud and sand. But for sediments to accumulate to a great depth it is necessary for the sea floor to subside as fast as the load of sediments is laid down upon it; otherwise the area fills up and becomes land, and sedimentation ceases. Hence the search for petroleum turns to the unstable belts of the earth's crust where there is delicate, prompt response to any change in load.

Also it is necessary for the organic matter that results from abundant marine life to be preserved until it sinks to the bottom and is

actually entombed in the accumulation of sediments. It must not be destroyed by oxidation or devoured by the marine scavengers that normally feed upon such materials.

There are two common environments frequently recurring in earth history in which organic matter, falling to the bottom of the sea, is effectively preserved for burial in the accumulating sediment: seas into which fine muds pour so rapidly that the stagnant bottom waters are too foul to permit the presence either of oxygen or of marine scavengers; and "desiccating" seas, those land-locked bodies of water all but cut off from the ocean proper, which are subjected to continuous evaporation so intense that they become highly concentrated and the various salts normally dissolved in sea water are precipitated, settle out, and accumulate as "evaporites"—limestone, dolomite, salt, anhydrite, etc.—on the sea floor. The waters of such seas become so salty that no life and very little oxygen are found in them, except in the surface layer which is diluted by rainfall and by constant or periodic inflow of fresh sea water from the adjacent ocean.

When we survey the earth for evidence of conditions in the past which would best fulfill these specifications for rich and extensive petroleum resources, our attention is soon drawn to the unstable belts, covered much of the time by shallow seas, which lies around the margins of the main continental platforms, between them and the great oceanic deeps. We note particularly the shallow depressions in the earth's crust, which throughout much of the earth's history have separated the several continents at their points of closest approach.

The best known of these troughs or depressed segments between the continental masses is the region now occupied in part by the Persian Gulf, the Mediterranean, Red, Black, and Caspian Seas, lying between the continents of Africa, Europe, and Asia; another conspicuous basin occupied by land-locked seas is the site of the Gulf of Mexico and the Caribbean Sea between the continents of North and South America in the Western Hemisphere; a third is the shallow island-studded sea lying between the continents of Asia and Australia in the Far East.

Through one geologic cycle after another these intercontinental depressions have been filled with shallow, land-locked seas, teeming with marine life, into which sediments poured rapidly from the land on all sides. Frequently, too, these depressions have been the sites of "desiccating" seas. The earth's crust beneath them is unstable or mobile and yields readily to stresses. Altogether these depressed zones between the continents seem admirably constituted to serve as natural reservoirs for the petroleum resources of the earth; and as soon as we look for petroleum in these regions we find abundant evidence of its presence.

The earliest historical records of the Near East refer to bitumen, burning springs, eternal fires, and other phenomena which unmistakably indicate petroleum and natural gas escaping at the surface. In modern times this region has developed the outstanding petroleum reserve of the earth, Russia's greatest oil fields are situated here, as are the famous oil fields of Iran and Iraq, owned largely by the British. Arabia, where exploration was undertaken for the first time by Americans only a few years ago, has already built up very large proved reserves of petroleum, and undoubtedly other important discoveries will follow. The important oil fields of Egypt and Rumania fall within this area.

Next to the Near East in importance are the environs of the Gulf of Mexico and the Caribbean Sea in the Western Hemisphere. Around the northern shore of the Gulf of Mexico are situated fully one-half of the total proved reserves of the United States. The tremendous past production of Mexico, Colombia, and Venezuela has come from the land fringe along the western and southern margins of this region. Further exploration in all these countries is certain to yield many new discoveries.

In the shallow depression between the continents of Asia and Australia in the Far East are the great oil fields, owned largely by the British and Dutch, on the large islands of Borneo, Sumatra, Java, and New Guinea.

If we accept the prewar estimates of the Russians that their proved reserves of petroleum are of the order of 45 billion barrels, the total proved reserves for the earth may be safely placed at somewhat more than 100 billion barrels. Fully 90 percent of these proved reserves lie in these three intercontinental depressions, and it is generally conceded that these regions also include the best territory by far for further exploration for petroleum.

There is a fourth great depressed segment of the earth's crust between continents which, except for the forward-looking Russians, has escaped any real consideration so far by the world's petroleum industry. This region lies between the continents of North America, Europe, and Asia. It covers the North Pole and is occupied by the Arctic Sea, a land-locked body of water into which sediments have been transported by the streams draining three continents throughout much of geologic time. We are accustomed to think of the waters covering the North Pole as the Arctic Ocean and our maps commonly designate them as an ocean, but they are in reality a land-locked sea, a fact long recognized by the Russians and other European peoples.

Evidences of petroleum are conspicuous at many places along the coasts which encircle the Arctic Sea. Near Point Barrow in northernmost Alaska there are copious oil seepages. At Fort Norman, 65°

north latitude, on the lower Mackenzie River, in northwestern Canada, a major oil field has recently been developed. On the islands north of the mainland of western Canada seepages of petroleum from the rocks at the surface were noted by Stefansson during his Arctic explorations. At numerous localities marked by surface escapes of petroleum and natural gas along the Arctic coast of Siberia, over a distance of 3,000 miles, Russian engineers have been engaged for years exploring for and producing petroleum.

The geological character of the Arctic region and the evidences of petroleum in the rocks that make up the coasts of the Arctic Sea both justify the belief that this region will eventually prove to contain some of the important petroleum resources of the earth.

As long ago as 1888 Edward Orton, a distinguished geologist engaged in a study of the petroleum resources of the State of Ohio observed: "It is obvious that the total amount of petroleum in the rocks underlying the surface * * * is large beyond computation." Since Orton's time we have extended our exploration for petroleum much more widely over the earth and, although we have not as yet even begun to exhaust the possibilities, we have already learned much to substantiate his conviction that the total amount of petroleum in the rocks underlying the surface "is large beyond computation." Nevertheless the belief persists that our petroleum resources are on the verge of exhaustion. Even though we have been obliged repeatedly to revise upward our previous estimates of their probable volume, we still fear imminent shortages of petroleum products. Will nothing we have learned serve to dispel this extreme pessimism?

Petroleum and coal, our mineral fuels, are fossil sunlight of 2,000 million years of earth history. In our natural resources of coal there is preserved for us part of the energy of the light which has bathed the land; in petroleum we recapture some of the energy of the sunlight which fell upon the adjacent waters. The coal resources of the earth we have measured, and we can calculate their volume with reasonable accuracy, a minimum quantity which runs into thousands of billions of tons—7,500 billion long tons. But the petroleum resources of the earth, which we cannot as yet measure, we refuse to think of as more than a few tens of billions of tons—less than one-third of 1 percent of our proved coal resources. Why do we believe there is so much less petroleum than coal in the earth? Was the life in the old seas so much less abundant than that on the land?

In recent years Parker Trask and others have made extensive investigations of the sedimentary rocks of the earth. We know that of the present land surface, some 60 million square miles, more than one-third is composed of sedimentary rocks; that is to say, an area of 22 million square miles of the present land surface of the earth has been covered

by seas at times in the past. Of this total area of former sea floors the rocks comprising about 6 million square miles are of a general character which make them of first-class promise for petroleum; they are present in great depth and are otherwise favorable for the occurrence of petroleum. The remaining area of 16 million square miles may also contain petroleum, but its general character is less promising and it is rated of secondary importance.

Among other characteristics of sedimentary rocks Trask sought to determine the organic content. In this research he examined the rocks which constitute the floors of existing seas as well as those of former sea floors. The rocks from the floor of the deep ocean proved to contain but little organic matter. But rocks formed in seas, near shore, were found to be much higher in organic content. Of the rocks now forming on the floor of the Black Sea, for example, organic matter constitutes more than 35 percent by weight. In the rocks from the floors of former seas Trask found the organic content to range up to 10 percent by weight, averaging 1.5 percent. Trask estimated the average organic content of the rocks in the floors of all present seas at 2.5 percent by weight.

Do these estimates promise enough organic matter to constitute source material for petroleum resources larger than we customarily reckon on? Let us confine our attention to the area of sedimentary rocks of first-class promise for petroleum, some 6 million square miles, excluding the remaining 16 million square miles entirely. Let us consider only that portion of the first-class area which is within easy reach of the oil man's drill, eliminating all possible resources more than, say, 7,000 feet beneath the surface, despite the fact that a large proportion of our present supply of petroleum comes from greater depths. Let us apply to this restricted portion of the sedimentary rocks of first-class promise for petroleum only the average organic content estimated for the floors of all existing seas.

Even on this minimum basis we obtain an estimated quantity of organic matter so large as to baffle comprehension—a quantity 200 times greater in weight than the total coal resources of the earth! If only one-half of 1 percent of this organic matter had been converted into petroleum, concentrated and preserved for us in the natural reservoirs of the earth's crust, our total petroleum resources would equal our total coal resources. If only one-tenth of 1 percent had been so preserved for us, our total petroleum resources would still be 60 times greater than all the petroleum we have so far discovered: that is, all our past consumption plus all our proved reserves.

In view of these figures it is not unreasonable to suspect that the problem we face is not a dearth of petroleum in the earth's crust so much as our failure to explore adequately and develop the resources

that are as yet undiscovered. If we now set ourselves to the task all over the earth as effectively as we have already done in our country we should be able to establish tremendous additional reserves. At any rate, if our total petroleum resources are as limited as we fear they may be, the explanation does not lie in any original lack of organic source material in the sedimentary rocks of the earth's crust. A very small fraction of the organic matter originally present in the most promising rocks would have sufficed as raw material for a great deal more petroleum than we have as yet discovered.

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WOODS AND TREES¹

PHILOSOPHICAL IMPLICATIONS OF SOME FACTS OF SCIENCE

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Some of you, I am sure, are wondering why a zoologist should presume to discuss a subject which apparently lies within the domain of the botanist. Of course to be strictly zoological I might have used the words formicaries and ants, but no one before me has said, "One can't see the formicary for the ants," and I do not presume to establish a saying.

I have had considerable experience instructing the general arts college student, the student who takes zoology as a college requirement and without thought of continuing in the field beyond the limits of the course. Each year at about this season, after all the tumult and the shouting of instruction have died down, in the wee small hours of the fading academic year, I take stock and ask myself in troubled seriousness, "What have I conveyed to my charges?" Facts, most certainly; but facts without their significance are as food without vitamins. One is filled but does not thrive. Hence, I query, have I been content to show to my students merely the trees of fact, each after each in all their intricacy of detail, or have I also taken them to a vantage point and shown them the beauty and majesty of the forest? Have I, in other words, taken full advantage of the opportunities which President Brown of Denison at our last meeting so eloquently ascribed to the instructors of science. You will remember that in the course of his remarks he humorously itemized the tongue-twisting terms that met his gaze as he reviewed the requisitions of his scientific staff. President Brown, however, saw beyond the terms and the facts they represent. He saw them as a means, not as ends. Unfortunately, some members of our scientific fraternity, not to mention the man in the street, see only the terms. Nothing is so revealing, so pathetically revealing, as the desperate efforts the casual acquaintance makes to find a common ground of

¹Address of the retiring president of the Ohio Academy of Science delivered at the annual meeting of the Academy held in Columbus, Ohio, April 30, 1943. Reprinted by permission from the *Ohio Journal of Science*, vol. 43, No. 4, July 1943.

conversation once he discovers you are a zoologist. All too often he amusingly, likewise tragically, attempts to recall a name—oh, yes, he says, I studied zoology once. Let me see, what is the name for oysters and clams? * * * That man has seen the trees. I wonder whether he was ever shown the woods; whether he was trained in anything but bare facts. And I wonder too whether, perhaps still more unfortunately, the significance of significances was ever appreciated by his instructors.

The trees and not the woods loomed large in the remarks made by a colleague of mine, a purveyor of the humanities, on the occasion of a round-table discussion between a faculty group and students on the ever-recurring topic of science and religion. The immediate question at issue was the relation of scientific facts to religion. My colleague was of the opinion that the two could be in no wise related. By way of illustration he pointed to the facts of meteorology; certain conditions of temperature, moisture, atmospheric movement we know result in rain. How can that knowledge possibly have any connection with religion, he queried. The answer, as we well know, is simple. This certainty of results which the meteorological facts represent takes much of the mystery and consequent uncertainty out of the comings and goings of the weather. To just that extent we feel secure and in harmony with the powers that ride the storm.

My colleague's query did double duty. It revealed the barren trees of both science and religion but the woods of neither. The fundamental yearning which the appeal to religion strives to fulfill is the yearning for security, a yearning which grips all of us. We tremble before the overpowering uncertainties of enveloping fate, the unknowable, and strive to achieve a harmonious relationship through religious experience. The woods, which apparently neither the scientific nor the religious experiences of my colleague had revealed to him, were that just as the all-compelling quest manifested through religion is the quest for security, so the all-embracing fruit of science is to afford security; the security that frees from the bonds of uncertainty and superstition and soothes the troubled soul with the peace that passeth understanding.

This doctrine of security, the teaching that we live in an environment ordered by dependable, understandable principles is as old as science itself, the leit motif that has threaded its guiding way through scientific thought throughout the ages from the times of the early Ionian teachers to the present. As F. H. Pike² reminds us in a published note within the year, "One great change which occurred in the period from Thales to Plato was the substitution of a world, perhaps even a universe, of law for the older world of caprice." And with it

² Science, April 24, 1942.

there was born a new thing, "science," which as Burnet¹ so aptly defines in his survey of Greek philosophy is "thinking about the world in the Greek way."

To return to my colleague and, I fear, to many others like him, what a woeful void there must have been in what he reaped from science, perhaps also in the guidance offered him by his mentors. One is moved to paraphrase the biblical interrogation, what doth it profit a man to gather the facts of science and lose its soul?

One group of scientific facts, its bare, gaunt trees stripped of their pleasing foliage, tells us that every particle of matter is attracted by every other particle in proportion to the product of the masses and inversely as the square of the intervening distances. These few words represent a vast number of subsidiary facts and a prodigious amount of painstaking effort in their formulation. It is known to all who mull them over that they explain the floating of a mote of dust to the ground and in the same breath the grand movement of the planets through space. I am wondering, however, how many of those who have burnt the midnight oil in mastering these facts, how many of our students, indeed perhaps, how many of their instructors and how many of our friends in the humanities like my colleague of the religious discussion have been taken to a mountain top from which they have been able to see that these same facts have served also as a guidepost in our quest of the ultimate, in molding man's interpretation of his universe, in orienting himself in time and space; that they have been one of the things which has helped to satisfy man's wonder, the awesome wonder that comes over one as he gazes into the depths of a star-studded winter sky where wonder leads to wonder and one is moved to breathe the thought, "What is man that thou art mindful of him?"

As Sir James Jeans⁴ points out, "The law of gravity was important not so much because it told us why an apple fell to the ground or why the earth and planets moved around the sun as because it suggested the whole of Nature was governed by hard and fast laws—in the light of Newton's work—Man began to see that he was free to work out his own destiny without fear of disturbance from interfering gods, spirits, or demons." Or again to partly paraphrase Dampier,⁵ Newton's reduction of the phenomenon of gravity to mathematical terms, coupled with the work of Copernicus and Galileo, in one grand sweep validated terrestrial mechanics in celestial spaces and eliminated with finality the Aristotelian and medieval doctrine that "the heavenly bodies are divine, incorruptible and different in kind from our im-

¹ Early Greek philosophy, 4th ed., 1930.

² Scientific progress.

³ Sir William Dampier, A history of science, 1933.

perfect world." The effect was even deeper and struck at the very roots of religious beliefs in that it was made "impossible any longer to gaze into heaven just above the sky, and to shudder at the rumblings of hell beneath the ground." Consequently, as Brett^{*} comments, "The seat of religious belief was thus moved from the heart to the head; mysticism was excommunicated by mathematics, * * * the way was opened for a liberal Christianity which might ultimately supersede traditional beliefs."

Incidentally a statement like that is indeed comforting to a zoologist. It lifts from his shoulders some of the burden placed there by the populace for having undermined ancestral beliefs.

Biology's central contribution to human thought has been the doctrine of organic evolution. This doctrine has brought coherence and order and significance to a multitude of otherwise apparently disconnected facts and theories within the field of biology itself and has opened up wide vistas of vision in other fields as well. It is undoubtedly superfluous to mention this to a scientific assemblage such as this, but there are scientists, even biologists, who tend to belittle the importance of evolution in the scheme of instruction. And here again I am moved to wonder whether we see the woods as we look at the trees; whether we consider the fact of the evolutionary origin of animals and plants as an end in itself and the meticulous details of evidence as ends in themselves or whether we look upon them as means to a broader end. As ends in themselves they are probably pleasant bedtime stories, if you like that kind of story. They are facts and add to one's store of such things, if your hobby is making a collection. If that is the spirit in which one presents the matter embellished for good measure with much precise detail, I fear that in the words of the philosopher, Irwin Edman, once applied to some of the humanities, it will be shortly "dying of anemia, of archeological hardening of the arteries and will become a corpse handled conscientiously by solemn morticians."

As means to an end the formulation of the doctrine of organic evolution, like the formulation of the principles of gravity, has served as the factual basis for a reorientation of human conceptions. If Newton paved the way for a liberalized Christianity, Darwin has paved the way for a liberalized sociopolitical outlook. The doctrine of organic evolution has once and for all destroyed the concept of the immutability of human institutions as well as of animal bodies. It has destroyed finality. If man as an animal is the product of change, his institution, the state, as a sociopolitical organization is not immutable. What served the purposes of our fathers may not of necessity serve ours. And so also have we been conditioned to discard the concept of absolu-

^{*} G. S. Brett, Sir Isaac Newton, 1929.

tism in the field of economics. With changing times come changing economic principles.

Organic evolution with its handmaiden, natural selection, has destroyed the sociological equalitarianism of the French Revolution. All men may be equal before the law; they are not equal before the bar of life. Gone, too, is the categorical dictum as a basis for morality and in its place has come racial experience, those standards which have survival value for the race. Morality in this light comes to mean allegiance to that code which will enable one's countrymen to live and to have life more abundantly. For those who may mourn the passing of the categorical standard, let me say that racial survival is a far more exacting standard than one which, perchance, permits of compensation by doing penance. The youthful monkey merrily swinging from limb to limb who misjudges his mark gets no second chance and leaves no descendants. It is, indeed, easier for a camel to pass through the needle's eye than to cheat the laws of life.

There is tonight no time, even if this could be considered an appropriate place, in which to trace all the ramifications of our racial experience as a standard by which we may order our lives. However, I should like to enlarge upon one phase of our experience which does appear to be peculiarly applicable to the present state of world affairs. Julian Huxley,⁷ in discussing man's achievements points out, as have others, that "the next step of greater control must be over man himself * * * through (among other methods) doing away with nationalistic drives and superimposing an international form of government on the world." To a biologist there straightway comes the question, what evidence have we that cooperation is any more successful than isolation as a biological method? Has not the arch isolationist, *Amoeba*, survived for millions of years and have not thousands of other rugged individualists been successful among the animal hordes? That interrogation immediately poses another—what is success? And to answer one must differentiate between survival and mastery. An animal, all of us, may survive through a variety of devious subterfuges and expedients, the common mark of which is that they entail subservience. However, success in fullest measure is mastery over conditions. If organic evolution has any significance it is the story of how living material has, through the cooperative actions of its subdivided units, approached, if it has not yet attained, mastery.

I am fully aware of the fact that organic evolution does not of necessity proceed along a straight-line principle, that life has followed a thousand and one devious pathways and on occasion has even retrogressed; but the fact remains, nevertheless, that at each level on which

⁷ *Man stands alone*, 1940.

there has been a closer approach to mastery that approach has been accompanied by a greater division of labor and a closer coordination of the constituent units until in man, the master, they have become woven into an intricate pattern of cooperating parts. At the opposite extreme lies an ineffectual, single-celled droplet of living material exemplified by *Amoeba*. Organic evolution is thus history, as much a part of our history as is the history of the written word, and as such, in fulfilling one of its functions, it points out the road we have trod and lights the way that lies ahead.

I am a zoologist, but for a moment I should like to turn historian, that man who has been termed by Schlegel a prophet looking backward, and as such a prophet refresh your memories by briefly tracing the steps of this story as others have done before me.

It can begin with *Amoeba*, a creature which epitomizes individualism. Not even in the commonly shared function of reproduction is it dependent upon another for assistance. A thousand and one changes have been rung on this isolationist-individualist theme among its fellow protozoans, each change having brought survival but no shred of mastery.

One of the early mutations leading out of the protozoan doldrums was that which resulted in causing proliferating cells to remain clustered together, and as such clusters to cooperate in the form of tubular units; a condition exemplified in varying degrees by the *Porifera* and the *Coelenterata*. The rewards were those that come from numbers and elementary divisions of function. This condition was followed by an innovation which resulted in dense, compact and solid masses of cells being able to exist as a single unit exemplified by our friends and tormentors, the flatworms. This state of affairs was accompanied by greater diversification in the constituent units and preeminently by rectilinear locomotion.

The next steps—three of them—in this mutating series were particularly significant; the development of distance receptors, the device which produced essentially compound animals, and the accompanying delegation of authority to subcenters which thus made possible the rapid and efficient control so characteristic of the metameric groups.

Metamerism is as far as life has gone in the way of physically compounding units. The compounding has continued but on the psychological level, or social level if you wish. If we are to consider psychological reactions as a specialized manifestation of physiological states, the continued compounding which we term our social organization is fully as much a physiological process as were the physical unions just outlined and as such must be considered a direct continuation of this compounding tendency, a continuation made possible by the development of distance receptors.

In saying this, I am mindful of those who maintain that social organization is not comparable to corporate organization. I am inclined to think the difference is not so much a matter of principle as of means. In the one case the constituent units have been held together by bonds of physical contact, in the other they have been as firmly held by the influence of distance receptors. Emerson,^{*} the ecologist, has recently expressed the view that, "Regardless of how one interprets the unity of the more complex human societies, the human family, and other family systems, are real cooperative, supra-organismic entities. * * * Society is merely a manifestation of fundamental life attributes which are shared with other biological systems (e. g., multicellular organisms) and the division between the social and the non-social is not sharp." Jennings^{*} goes further and points out that there is much to be said in favor of the conclusion that "mankind is a single great organism temporarily divided into pieces—the individuals." Through this device the essential benefits of physical union are retained and become enriched by the advantages to be derived from mobile units. The study of organic evolution is, indeed, from one standpoint essentially a study in populations. Much can be said in support of the conclusion emerging from such a study, that in its animal phases at least unitary masses of protoplasm, whether these units be cells or bodies, under similar conditions follow essentially similar principles of group organization.

The social organization of the corporate population has, as you know, followed along two lines, the one illustrated by certain insects, the other by man. Among insects the culmination is reached by the ants and the termites, those individually defenseless creatures and toothsome morsels for many a foe which have through cooperation lived from the Tropics to the borders of the Arctic.

Our own social structure is an even more intricate and widespread culmination of increasingly interdependent component units the progress of which has followed one unswerving path marked by the milestones of free cells, tissues, organs, organ systems, compound organisms, then families, tribes, kingdoms, empires, major alliances, and still it holds its course into the future. Faintly outlined as yet but apparently on our course lies some type of world union. This last prophecy may be branded an ultra-utopian fancy, but it must not be thought that the pyramiding of units I have just traced, whether in the field of physical union or sociopolitical associations, came without a struggle, without false starts that led up blind alleys or ended in stark failure.

^{*} A. E. Emerson, Denison Univ. Bull., December 1941.

^{*} Journ. Soc. Philos., January 1937.

For those who may be faint-hearted, the fact to be kept in mind is that with all the difficulties that beset the way, union was eventually accomplished, that with each union, with each sacrifice of self, with each restriction of liberty, there has been a stride toward greater mastery, toward a fuller, more abundant life for the whole. At one extreme is individualism, represented by Amoeba, beholden by neither jot nor tittle to anyone, groveling withal in the slime and swept hither and yon by every whim of nature. At the other extreme are millions of interdependent cells united in the form of men who, in turn, through their combined efforts have overcome the sufferings of famine, the scourge of pestilence, the barriers of distance, the mysteries of the air, yes, even the intricacies of creative synthesis. Optimism for the future is well expressed in the words of the paleontologist, Lull,¹⁰ who writes, "The great heart of nature beats, its throbbing stimulates the pulse of life, and not until that heart is stilled forever will the rhythmic tide of progress cease to flow."

Among the social insects the price paid to the group for the benefits of cooperative action is that the individual be born to a class and have stamped upon him unalterably the form of his station in life—worker, soldier, king or queen—there to remain toiling dutifully without will or choice that the group may survive. That is strait-jacketed, inflexible efficiency, not inviting to those of us outside the pale of Nazi or Fascist rule. It has, moreover, fallen short of control, probably because its morphological inflexibility is paralleled by inflexibility of nervous reaction.

There is no gainsaying that one of the most patent of biological principles requires that when individual and species conflict, it is the individual that must give way even to the extreme of life itself. For us the demands of society are indeed becoming more and more exacting; we are individually being held to a closer and closer accounting. There is ever-increasing regimentation. But we of the vertebrate line are fortunate in that we belong to a type of social organization which permits its members the opportunity of realizing their responsibility to the group and of doing their duty voluntarily and without compulsion. If we but will, therein lies our avenue of escape from the fate of an enforced regimentation analogous to that of the insects.

The responsibility which rests upon us individually arises from the division of labor inherent in society. Each sequence in the evolutionary progress of living material from microscopic unit to dominating mass involved more and more detailed division of labor and with each advance there came increasing responsibility. For instance, in an unspecialized body like that of a sponge the entire body, as you well know, can be taken apart cell by cell and then the whole mass or any

¹⁰ R. S. Lull, *Organic evolution*, 1929.

portion of it can again take on the form and function of a sponge. Here, it matters little whether any one or a group of cells fail. At the opposite extreme in man, the loss of an islet of cells in the pancreas means death. Clearly specialization and responsibility go hand in hand.

The inexorable demands of nature that each do his duty to his kind need not of necessity mean that before us lies a future in which we shall be slaves to the State, Nazi-fashion. A slave performs his duty without choice, has no voice in his fate. Before us lies the opportunity to both exercise our choice and discharge our duty. If, however, we do not so choose, we shall have responsibility and no freedom, no chance to direct our fate. There are even now those among us who would impose the prototype of insect rigidity upon our form of social organization. Its most extreme exponents are the followers of Nazi philosophy. Rauschning¹¹ reports Hitler as declaring, "There will be a master class * * * also a new middle class * * * and the great mass of the eternally disfranchized. Beneath them still will be * * * the modern slave class. * * * Universal education is the most corroding and disintegrating poison that liberalism has ever invented for its own destruction." Carrel¹² has expressed somewhat similar views, as for instance, * * * "The democratic principle has contributed to the collapse of civilization in opposing the development of an elite. * * * modern civilization is incapable of producing people endowed with imagination, intelligence and courage. * * * the equality of their (man's) rights is unequal."

It is true that there are biological differences among us which cause difficulties in a democratic state, but gene distribution is such that few are wholly of inferior quality and few, if any, of wholly superior stuff. The mechanism of transmission and interaction of genes further complicates the picture. And who is to differentiate what is good or how? As Jennings suggests, "One of the greatest difficulties in the way of effective human action lies in the lack of agreement as to the end to be attained. * * * perhaps the greatest difficulty of all lies in the lack of agreement as to the individuals or groups that should benefit by the action to be taken."

The course upon which the physically undifferentiated and mobile fabric of the vertebrate social organization is set does not of necessity demand a society strait-laced and closely regimented in which freedom of action is surrendered. It does demand and will exact the surrender of action for self alone. It does place upon us unalterably responsibility to our fellow men. The failure on the part of many of us, most of us I fear, to realize this fact has been an important source

¹¹ The voice of destruction.

¹² Man, the unknown.

of our present unrest. With a sense of allegiance to the group in the spirit of that larger self-interest which realizes that the greatest good for the individual is inextricably bound up with the good of the group, there need be no fear of enforced regimentation. Unlike the strait-jacketed insect civilization, such realization of individual responsibility permits us freedom to pass from stratum to stratum as the cast of the genes may decide, and leaves us the stimulus of individual initiative. The specializations of society without a sense of responsibility lead to the limited privilege of an unbridled, cancerous growth; specialization with a sense of the common good leads to the harmony of a well-ordered body.

As I come to the end of my remarks let me mention once again my thoughts at the close of the academic year, my interest in the trees of fact and the woods of significance. I have, as you see, directed your attention to but a few examples. First among them was the very soul of science, the sense of security which scientific facts convey. Second was the influence of what may appear to be purely physical principles upon the liberation of man from the bonds of religious ignorance; third, the significance of the facts of evolution as a guiding light upon our way and finally the significance of the individual's obligation to the group. I have discussed them because with all the immediately practical applications of fact that can be made, which are truly many and important, such applications alone are not sufficient. The instructor in science has not completely fulfilled his responsibility to those who come to him for guidance unless he has pointed out the wider significances. These broader applications which carry us into the realm of ideas are required to satisfy fully that age-long quest which Sir William Dampier has so richly clothed in these words:

At first men try with magic
charm

To fertilize the earth,
To keep their flocks and herds
from harm
And bring new young to birth.

Then to capricious gods they turn
To save from fire or flood;
Their smoking sacrifices burn
On altars red with blood.

Next bold philosopher and sage
A settled plan decree,
And prove by thought or sacred
page
What Nature ought to be.

But Nature smiles—a Sphinx-like
smile—

Watching their little day
She waits in patience for a
while—
Their plans dissolve away.

Then come those humbler men of
heart
With no completed scheme,
Content to play a modest part,
To test, observe, and dream.

Till out of chaos come in sight
Clear fragments of a Whole;
Man, learning Nature's ways
aright,
Obeying, can control.

BIOLOGY AND MEDICINE¹

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My subject this afternoon is "Biology and Medicine," but I think a more accurate wording would be "Medicine and Other Phases of Biology," for to my mind medicine is a branch of biology. Webster's Dictionary defines medicine as the science and art dealing with the prevention, cure, or alleviation of disease. Biology is the science of life. Disease might well be defined as life out of balance, and is in a strict sense a biological process. Whether it be an attack by micro-organisms, or improper functioning of glands, or congenital misformation or maladjustment, or injury by poison or bullets, disease processes are in the last analysis nothing more than cells, tissues, or organs that have suffered injury and so not only fail to perform their normal functions but in most cases interfere with the normal functions of other parts, more often than not of the entire body.

Of the two great divisions of medicine dealing respectively with treatment and with prevention, the former is much the older. It is far easier to observe the effects of treatment on a person suffering from a malady than it is to understand why someone else escaped it. Some knowledge of curative or alleviative medicine was possessed by our cave-dwelling ancestors; in fact, it is instinctive in many lower animals. It gradually grew up as a sort of folklore from a slow process of trial and error, added to the instinctive knowledge acquired from prehuman ancestors.

With the growth of belief in the supernatural, by which man satisfied his developing desire to explain things, medicine became largely theological. Priests and physicians were one. They conceived disease as the work of devils, gods, or spirits which had to be appeased by sacrifices, confused or circumvented by charms or incantations, evicted by emetics, cathartics, or bloodletting, or enticed to escape by means of holes in the skull, nasty medicine, or other devices. It is since the days of our Pilgrim Fathers that we have learned that it is more effective to control typhoid and cholera by boiling water than by boiling witches.

Although belief in the instrumentality of demons and witches in causing disease persisted for a long time, since Hippocrates more en-

¹ Public lecture delivered at The Rice Institute in the spring of 1943. Reprinted by permission from The Rice Institute Pamphlet, vol. 30, No. 4, October 1943.

lightened individuals have recognized at least some kinds of disease as natural processes. From that time to the present medicine has been primarily biological instead of theological or metaphysical. Some of the original ideas were, as would be expected, very far astray; for example, the theory that Hippocrates inaugurated and Galen expanded that proper proportions and relations of four humors of the body were responsible for health or disease. According to this theory people were sanguine, phlegmatic, choleric, or melancholic in temperament depending upon which of the four humors predominated. Erroneous as it was, this theory was a long step forward in that it focused attention on natural instead of supernatural causes, and on caring for the patient instead of appeasing devils.

Hippocrates was also an exponent of the great biological principle that nature is the greatest physician of all. Left alone, an organism attempts to repair damages to its parts, to adjust itself to any unbalance in structure or function that has been entailed, and to fight off attacks by parasites. The role of the physician is to aid the organism in these attempts. In many cases this involves nothing more than augmentation or speeding up of natural biological processes that the organism itself would employ, such as stimulation of immunity, supply of additional antibodies, provision of new tissue or fluid in the form of grafts or blood transfusions, supply of abundant vitamins, regulation of hormones, removal of unhealthy tissue, and protection against invasion by micro-organisms. In some cases it involves methods which are entirely foreign to the natural processes of the animal body, but which aid and abet these processes, such as the use of stimulants, anesthetics, specific drugs, X-rays, radium, or heat.

The speeding up of natural processes of repair or adaptation is applied biology. It involves a thorough knowledge of the normal biology of the human body—its anatomy and all phases of its physiology. Strangely enough, even knowledge of the gross anatomy of the human body was extremely sketchy and mostly wrong up to the middle of the sixteenth century.

Galen, of the second century A. D., was the father of anatomy for years, but he was a very poor father and his offspring was a very hodgepodge anatomy, arrived at from observations on the inner workings of monkeys, pigs, dogs, and cattle. For over a thousand years man was supposed to have a segmented breastbone like a monkey, a liver divided into as many lobes as a pig's, a uterus with two horns like a dog's, a hipbone flared like that of an ox, and a heart with pores between the right and left ventricles. If in the meantime any errors were discovered in Galen's descriptions the fault was always thought to be either with the patient or with the later observer. When Vesalius, in the sixteenth century, showed that man's hipbones certainly were *not* flared as Galen described them, it was thought

that they had undergone a change in the intervening centuries due to the habit of wearing tight trousers.

The study of anatomy was retarded greatly by religious and civic taboos on dissection of human bodies, but Vesalius spirited skeletons from beneath gallows and was not above occasional clandestine disinterments. He made important contributions to human anatomy, and did much to start other physicians consulting nature instead of Galen. Vesalius even reached the threshold of the discovery of the circulation of the blood, but this great milestone in the history of medicine was planted by Harvey in the seventeenth century. Probably no other single physiological discovery has had such profound consequences. What a superlative age that was, to produce a Harvey, a Shakespeare, and a Galileo!

In the eighteenth century advances were more rapid. It was in that century that another great Englishman, John Hunter, discovered that if arteries are tied off the blood will find and develop new channels. Prior to that discovery aneurisms, which were distressingly common, were treated, if at all, by amputation of limbs. John Hunter also learned some of the tricks of grafting skin and bones.

In the next century, the nineteenth, two other fundamental biological principles—the cellular structure of bodies, and evolution—came to light. Both of these ideas contribute so much to our knowledge of the human body and how it works that a full evaluation of their significance in medicine would be almost impossible.

Even with all these advances in anatomy and physiology, nobody up to the middle of the seventeenth century had any good idea what disease was or whence it came. An important forward step was made in 1687 when two Italian scientists, Bonomo and Cestoni, showed that scabies was a disease caused by tiny mites burrowing and reproducing in the skin, and was spread by transmission of the mites. This was the first demonstration of a specific cause for a disease, and the first explanation of its spread, and was a clean break from the divine, humoral, or other ancient theories of the spontaneous origin of disease.

A few pioneering minds, a century or two ahead of their times, propounded theories of contagion, and spread of disease by dissemination of poisonous particles or gases, or even by invisible living organisms, but there was no experimental evidence, and these precocious ideas fell on barren ground. A true understanding of infectious disease had to wait for the discovery of micro-organisms and some knowledge of their nature.

Leeuwenhoek, a Dutch lens grinder of the seventeenth century, who invented a compound microscope capable of bringing bacteria within the range of visibility, is sometimes called the father of bacteriology, but I think he might more properly be called its midwife. He was one of the greatest explorers of all time. Magellan and

Columbus are credited with discovering continents, but Leeuwenhoek opened the door to an entire new world. Wherever he looked—in soil, water, food, excretions, or decaying materials—he discovered a host of micro-organisms that nobody had ever seen before or even suspected of existing. Modern explorers with electron microscopes are having a great time too, but their discoveries of molecules and viruses and of the minute anatomy of bacteria is hardly to be compared with the new world that Leeuwenhoek found under *his* microscope.

But I do not think that knowledge of the existence of insects makes an entomologist, or knowledge of the existence of stars an astronomer, so I hesitate to consider Leeuwenhoek the father of bacteriology. That honor, I think, should go to Pasteur who, within the lifetime of my parents, made bacteriology a science. He did it by providing final proof that germs, like all other forms of life, require parents, and come only from pre-existing germs. As long as it was thought that germs developed spontaneously from decomposing materials the bacteriologist was in as hopeless a position scientifically as a mathematician would be if the sum of two and two varied with the weather.

From the standpoint of the control and prevention of disease this was undoubtedly the most momentous discovery ever made by man, for it alone provided a solid foundation for practically all our public health work. On it rests all our theory and practice concerning contagion and infection, quarantine, sterilization, antisepsis, aseptic surgery, purification of water, pasteurization of milk, and almost everything else on which modern practices of public health and hygiene are based. Pasteur is rightly revered for his great contribution in proving the germ theory of disease, but this would have been of little value or significance without the final abolition of the idea of spontaneous generation, which for a long time extended even to maggots and mice.

Pasteur's fundamental discoveries led almost at once to practical applications. Lister in London was quick to apply them to surgery, and by very generous application of carbolic acid to himself, the patient, the bedclothes, the air, and even the floor, he brought about a very considerable reduction in the mortality from operations, which had previously been about 45 percent even in his expert hands.

During the eighteenth century Europe suffered from great epidemics of childbed fever—at one time it got so bad that in Lombardy it was said that for a year not one woman lived after bearing a child. Europe's lying-in hospitals for destitute mothers were humane in spirit only; in reality they were death traps. Oliver Wendell Holmes proclaimed childbirth fever an infectious disease, carried from patient to patient by physicians and midwives. Many physicians were incensed at the imputation that their hands were not clean, and Holmes's

ideas didn't make much headway. It was Semmelweis of Vienna who finally dealt the death blow to childbed fever as an epidemic occurrence, and proved that even an eminent gentleman's hands are not always clean. It is within the memory of many in this audience that aseptic surgery finally supplanted Lister's heroic antiseptic measures, and that surgeons began paying more attention to washing their hands before an operation than after it.

Some 20 years after Pasteur's demonstrations of the germ cause of disease and the final putting to rest of the theory of spontaneous generation, Robert Koch developed technical methods that made possible the easy isolation and study of particular kinds of germs, and then discovery followed discovery with almost incredible rapidity. In the short space of 15 or 20 years the causes of the majority of infectious diseases of man and animals were isolated and studied. The elusive and rather mysterious agents of disease that we call viruses, however, had to wait much longer for biologists and chemists to pry into their private affairs, and it is only now that very much progress is being made.

An infectious disease is, however, an extremely complicated phenomenon. The interaction of a parasite and its host is not a static thing like the interaction of one chemical with another, capable of simple description, and following a well-defined course. We may be too prone to think, because we know what organism causes a disease and something about its biology, that we understand the disease it causes. Nothing could be farther from the truth. We are dealing with the interaction of two organisms both of which are capable of an amazing degree of adaptation to changing conditions. Every change or adaptation in one entails further adaptations in the other. A disease may be compared with an organism—it is born, it grows, it adapts itself to environment, and it finally dies. During its life it is influenced by a host of environmental factors which may profoundly alter its course.

An infectious disease depends on the presence of a specific invading organism, but this may be only one of the necessary requisites. In almost every epidemic the number of healthy carriers—people who temporarily acquire a colony of the germs but show no evidence of disease—far exceeds the number of cases. In an epidemic of cerebrospinal meningitis healthy carriers of the organism that we say causes it may outnumber the clinical cases 20 to 1. In most epidemics of such diseases as diphtheria, whooping cough, dysentery, and even cholera, the ratio is from 5 or 10 to 1.

If disease develops in only one-fifth to one-twentieth of the people reached by a particular pathogenic germ, it is evident that there are other factors playing very important roles in its production. Among these are a proper balance of the glands of internal secretion, good

nutrition, especially with respect to vitamins, and the development of specific immunity or resistance. There can be no doubt that these same factors play a large part in determining the course and outcome of a disease after it has gotten a start. A physician, then, if he is to make the most of his effort to help in suppressing disease, must be far more than a dispenser of medicine. He must, indeed, be familiar with more phases of biology than are most biologists. He must understand anatomy, histology, general physiology, endocrinology, embryology, psychology, nutrition, immunology, and even genetics in order to have a proper understanding of his patient, and he must be a bacteriologist or parasitologist to understand the capabilities and vulnerabilities of the invading organism.

Some relations of heredity and genetics to disease have been known for a long time, but more progress has been made in genetic control of disease in plants and even in domestic animals than in man. Effects of genetic constitution of human beings on the course of disease and development of resistance are still very little understood, and still less is known about effects of genetic constitution of pathogenic organisms and means of altering it. Herein lies an almost untouched field with vast possibilities for the future.

Experimental breeding of mice has resulted in decreasing mortality from a particular disease from 82 to 24 percent in six generations, and to 8 percent over a period of years. In six generations of chickens mortality from fowl typhoid decreased from 85 to 10 percent. Recent studies indicate that alterations in genetic constitution comparable to mutations in insects and plants occur also in bacteria and even in viruses. In a period of a few hours many kinds of bacteria and viruses may reproduce in such numbers that if their rate of mutation is comparable with that thought true for fruitflies, each gene the bacteria possesses should mutate at least once. With even slightly favorable selection, replacement of the parent population by mutants is possible in short periods of time.

Viruses have many characteristics of genes, differing principally in their ability to move from cell to cell. There is evidence that the mutation of viruses is comparable with mutation of genes. The development of relatively nonpathogenic varieties of viruses or bacteria is the real basis for the production of effective vaccines against such diseases as smallpox and yellow fever, and probably for the rise and fall of epidemics of cholera and diphtheria. It has recently been discovered that the virus of infantile paralysis genetically altered by mouse adaptation, when mixed with the parent virus, has great power to protect monkeys from paralysis. What causes the protection is not yet known, but the result of this basic discovery may be very far reaching.

Concomitant with development of knowledge of causes of infectious diseases, immunology was beginning to make its contributions to the cure and prevention of disease. You are all familiar with Jenner's discovery in 1798 of the protective value of cowpox inoculation against smallpox. As the result of that there is probably no one in this audience with a pockmarked face, whereas in Jenner's day certainly one in four of you would have been so marked if indeed you were alive at all. Jenner, however, had no notion of how his method worked; he merely observed that it did, and risked the ridicule of the medical world by saying so, and the life of his own son by testing it.

Many decades later Pasteur, making the most of an accidental observation, laid a foundation for modern immunology by showing that agents of disease can be attenuated by various means to a point where they are no longer capable of producing serious disease, but still possess the power of stimulating immunity comparable with that produced by recovery from a real attack. Just as bacteriology opened the gates to knowledge of the causes and means of transmission of infectious diseases, so the birth of immunology opened the way to knowledge of nature's principal means of combatting them.

The contributions of immunology to the cure and prevention of disease are so numerous that I can mention but a few. As aids in diagnosis I may mention the tuberculin test for tuberculosis in cattle and man; the Shick test for susceptibility to diphtheria; the Dick test for susceptibility to scarlet fever; the scratch test for allergies to pollens, foods, or other substances; the agglutination tests for typhoid, dysentery, cholera, typhus, and many other diseases; the Wasserman, Kahn, and other tests for syphilis; the typing tests for the pneumococci of lobar pneumonia; and many others that are less well known but no less useful when needed.

As therapeutic aids I may mention antitoxins for diphtheria, tetanus, scarlet fever, and a number of other diseases, which have made deaths from some of these diseases under ordinary conditions nothing short of criminal negligence; the helpful injections of typed pneumococcus serum in pneumonia; the use of immune or convalescent serum in cerebrospinal meningitis, anthrax, measles, and most recently influenza; and the life-saving properties of antivenin for snake bites.

As preventive aids I need only call your attention to the wonderful records achieved by the use of vaccines against typhoid, paratyphoid, diphtheria, and more recently yellow fever. This once dreaded disease is now looked upon by the United States Public Health Service as of less consequence than the relatively mild and tolerated dengue fever, merely because our Government has a bank of a million protective doses of vaccine which it can release if ever a case occurs within our borders. In recent years success has also been attained in production of vaccines against typhus fever and spotted fever, the former of

which has hitherto been the scourge of every great war. In the present war man-made implements of destruction are more deadly than ever before, but there is no question but that this added deadliness is more than compensated for by protection from diseases, which, up to the time of the Spanish-American war, always wrought more havoc than the enemy. Such diseases as typhoid, dysentery, typhus, tetanus, and yellow fever have been shorn of their power by protective vaccinations.

Closely related to the field of immunology is blood typing, which has placed blood transfusion on a safe and sound footing, and made it as routine a procedure as anesthesia or surgical asepsis. In spite of the accomplishments in the field of immunology in recent years, I think we may confidently look forward to ever greater things in the years to come. Within the past 12 months success has been attained for the first time in the artificial production of antibodies in laboratory flasks. This may open the door to future developments which may surpass anything we have yet been able to hope for.

I wish now to turn your attention to another field of biology that has contributed enormously to medicine—the science of endocrinology. No sorcerer or magician of old ever dreamed of accomplishing the miracles that can be performed today by the application of knowledge in this field. Osler, speaking of the effect of thyroid extracts on those horribly misshapen, doltish creatures known as cretins, says, “Not the magic wand of Prospero or the brave kiss of the daughter of Hippocrates ever effected such a change as that which we are now enabled to make in these unfortunate victims, doomed heretofore to live in helpless imbecility—an unmistakable affliction to their parents and their relatives.”

The science of endocrinology was born of primitive beliefs in organ magic. When our remote ancestors began to indulge in the art of thinking and had reached the stage at which they could weave together a number of scattered observations and come out with a general idea, it was a natural deduction that the kind of food you ate was a big factor in determining what sort of person you were. Tigers were thought to be fierce because they ate raw meat; it was overlooked that a tiger fed on lettuce and carrots would undoubtedly be fiercer still, and that a meat eater *had* to be fierce to get his meat whereas a vegetarian could afford to be timid and fleetfooted. Such thoughts, traveling along a single track, eventually reached the conclusion that courage could be acquired from eating the hearts of courageous animals or men, intelligence from eating brains, and so on. The psychological effects undoubtedly provided ample circumstantial evidence for the truth of the assumptions.

Modern endocrinology began in 1889 when a famous French scientist, Brown-Sequard, claimed remarkable rejuvenating effects in him-

self from injection of gland extracts. His results, too, were probably psychological, but his prestige was such that his claims started a development in medicine that has had more profound significance than any since Pasteur's discoveries of the bacterial origin of disease.

The human body is a highly automatic, self-regulating mechanism. Nature's primitive means of regulation of the body of an organism is by chemical substances secreted by its tissues. Superimposed on this, later in evolution, is an involuntary nervous system, useful in making rapid and temporary adjustments that become necessary for a body with ever-increasing activities and more and more complicated relations to its environment. Still later in evolution Nature added a voluntary nervous system but very wisely refrained from giving it control over the internal regulation of the body. As Dr. Cannon remarks, we should be greatly bothered if in addition to attending to the business of other people we had to attend to our own. The internal affairs of the body are too important to be subject to a well-meaning but neglectful and incompetent intelligence, which would as likely as not be concerning itself with the flight of a golf ball when it ought to be attending to the rate of the heart beat.

The chemical method is still the fundamental means of regulation of the body. Chemicals produced by tissues, which we call hormones, control such functions as growth, development, metabolism, and reproduction, and adapt the body gradually to climatic fluctuations, variations in activity, nutritional changes, pregnancy, lactation, etc. The human body is one of the most thoroughly integrated and communistic organizations imaginable, every part sharing, according to need, with every other part, and each part influencing every other part. It is a prevalent view today that every tissue and organ in the body produces hormones or hormonelike substances that help in the integration of the entire organism. As bodies became more complex during the course of evolution, however, and the regulation more difficult, a number of special glands for production of particularly potent hormones were developed. These are what constitute the endocrine system. Some of the glands are completely separate organs having no other functions, such as the thyroid, pituitary, and adrenals. Others have developed as special tissues in already existing organs, as in the pancreas, liver, and sex glands.

The potency of these glands is almost incredible. They very largely determine what we are and how we behave. They dominate our physical stature, our mental development, our emotional status, our reproductive activity, the rate at which we live, and our ability to make use of our food. They are the architects of our bodies and the moulders of our character. A puppy deprived of its anterior pituitary gland may be converted from an aggressive, pugnacious creature to a whimp-

ering coward, and may be returned to its former state by pituitary injections. Injections of prolactin into rats with no trace of maternal instincts will fill them so full of mother-love that they will even mother baby squabs instead of eating them. One is led to interesting speculation as to whether injections of prolactin might not be a good alternative to execution for despotic dictators.

The hormones produced by the endocrine glands, some stimulating and some inhibitory, not only affect the body as a whole in many complex ways, but they interact with each other in such an intricate manner that we are still very far from ideal utilization of them, and we may look forward to a great extension in the future. Yet even now, only 50 years from the birth of the science, the use of hormones has revolutionized a large part of medical practice and has given new insight into many physiological processes, such as metabolic rate, sugar metabolism, blood pressure, menstrual disorders, psychotic maladjustments, adiposity, sexual aberrations, and reproductive difficulties.

Now let us turn to another contribution of biology to medicine—knowledge of nutrition. For lack of time I will pass briefly over many interesting discoveries connected with metabolism of proteins, fats and sugars, utilization of minerals, etc., though in passing I must pause long enough to mention a relatively new tool in physiological research—the use of ions tagged by means of atoms of unusual weight or made radioactive in cyclotrons. By this means it has been found that molecules in the body, even those supposed to be relatively stable in bones, teeth, or fat, are forever being shifted about and replaced by new ones. The body is even less stable than it was thought to be.

The most significant discoveries in nutrition, ranking close to the discovery of hormones in their importance to human welfare, were those of the vitamins. Since the days of leopard-skin dinner jackets and struggles with cave bears instead of dictators, man's ways of life have undergone many changes and so have his foods. With the development of agriculture and civilization his food became less varied and more highly manipulated. He began to live more extensively on grain, to store food for periods of famine, and to cook it. Later he began throwing away the vitamin-bearing parts of his cereals, developed a taste for refined sugar, protected himself from sunlight, and often lived for months without fresh fruits or vegetables. Beriberi, scurvy, rickets, pellagra, and night blindness attacked whole populations.

Except for the cure of scurvy by eating lemon juice or hemlock leaves some 200 years ago, nothing definite was known about these nutritional-deficiency diseases until Eijkmann began experimenting with diseased fowls in Java 45 years ago. Gradually during the last 30 years a whole alphabet of vitamins has been discovered, but it is

only within the last decade that they have been obtained in chemically pure form, and synthesized. Few people even today realize the importance of this. Although this country is probably the best fed in the world, I do not believe it is an exaggeration to say that 50 and possibly 75 percent of the American people do not have optimum amounts of all the vitamins they should have. They do not have scurvy or beriberi or rickets, but they have a host of minor illnesses or troubles that they need not have. Some British authorities have gone so far as to say that 99 percent of so-called common illnesses are directly or indirectly due to vitamin deficiencies. Allowing 100 percent expansion for enthusiasm, the figure is still impressive.

The common effects of vitamin deficiencies are such things as night blindness, susceptibility to colds, unhealthy teeth, poor appetite, gloominess, nervousness, and a tendency to fly into tantrums. An abundance of vitamins leads not only to a state of superhealth in people who have always considered themselves reasonably healthy, but it is of great help in recovery from acute or chronic diseases, repair of wounds, and resistance to infection. Even yet, many medical men tend to look upon synthetic vitamins as medicine rather than supplementary food, but gradually this is changing, and it is encouraging to see more and more foods fortified by added synthetic vitamins. Because of this and the more even distribution of vitamin-bearing foods by rationing, the general level of nutrition in England, in spite of several years of war, is better than it has ever been before. It is becoming more and more so in this country too.

The definition of medicine includes the prevention of disease as well as its cure and alleviation. Some attempts at preventive medicine were made when disease was supposed to be caused by demons, for it was a natural inference that if the demons could be ejected they might also be prevented from entering. With the development of the humoral theories, preventive medicine was almost completely forgotten, since no one had even guessed as to how the humors could be kept in order before they got out of balance. Prevention of disease is a phase of ecology, and involves knowledge of normal bodies and their relation to their environment, including climate, atmosphere, and geological formations, as well as relations to such fellow creatures as rats, mosquitoes, lice, hookworms, amoebae, and bacteria, to say nothing of viruses.

It is only in very recent times that anything whatever has been known about this phase of medicine. Only in a few instances have the processes of trial and error that led to curative and alleviative procedures led to practices that prevent disease. One of the first great triumphs in curative medicine was the discovery, in 1640, of the value of extracts of cinchona bark as a cure for malaria, but it was

not until the end of the nineteenth century that a basis for the prevention of malaria was discovered.

A few practices of primitive people suggest attempts, probably unwitting, to prevent disease. In India, for instance, I found a primitive tribe, the Santals, who never drink water directly from a stream or pond, but from a little hole in the sand a foot or so away, thus practicing sand filtration, one of the prime tools of modern sanitary engineering. The unfitness of natural water for drinking was recognized long ago. Cyrus of Persia carried boiled water for his troops 2,500 years ago. The low repute of water as a beverage even in the unenlightened middle ages is evidenced by a thirteenth-century writer who, describing the extreme poverty of Franciscan monks who settled in London in 1224, exclaimed, "I have seen the brothers drink ale so sour that some would have preferred to drink water." The head-hunting, carrion-eating Nagas of the Assam hills drink only a rice beer, carrying starters with them when they go on trips.

Preventive medicine as practiced at present has three principal legs to rest on: (1) the upkeep of natural resistance by general hygienic measures, including a proper hormone balance and optimum nutrition; (2) the artificial stimulation of specific immunity or resistance; and (3) protection against access of disease germs via water, food, air, or insect transmission.

The general principles involved in the first of these have been known for a long time, but the details have only recently been filled in by the discoveries with respect to hormones, minerals, and vitamins that I have already mentioned. I have already called your attention to the fact that in an epidemic only a small percentage of the individuals that are actually exposed develop a disease. The determining factors are the dosage of germs that gain access to an individual, and the natural resistance he has. The higher the natural resistance, the greater the dosage he can withstand.

The second leg on which preventive medicine rests, artificial stimulation of immunity, I have already discussed. On it we depend very largely for our protection against smallpox, diphtheria, tetanus, rabies, yellow fever, spotted fever, typhoid fever, and many other diseases.

The third leg on which preventive medicine rests—protection against dissemination of germs—I have so far said little about, but here enormous strides have been made within a short space of time.

Famous in sanitary history is the case of the Broad Street pump in London in 1854, around which centered an explosive outbreak of cholera. After everything from the chemical nature of the soil to dust bins in cellars had been investigated, the relationship between drinking water from the well and attacks of cholera became clear. Nature had provided a grim lesson out of which grew modern sanitary engineering. In the intervening 90 years modern water purifi-

cation and sanitary sewage disposal have developed. Whereas in 1900 the American death rate from typhoid was 36 per 100,000, today it is about 1 per 100,000, and in 1942 more than half of our large cities had not a single typhoid death.

Milk and food sanitation are even more recent developments. Even 25 years ago a child ran the risk of acquiring disease every time he drank a glass of milk; today the greater part of the milk supply in almost every city is pasteurized, and many cities can boast of having no raw milk.

Just 50 years ago two American workers, Smith and Kilbourne, laid the foundation stone for medical entomology when they demonstrated the transmission of a disease—Texas fever of cattle—by means of a tick. Five years after that the mosquito transmission of malaria was proved and then, at the turn of the century, came the brilliant work of an American Army commission in Havana, proving the transmission of yellow fever by mosquitoes.

Today medical entomology plays a large part in our lives. By control of insects, ticks, or mites we are able to control, in some cases almost to exterminate, many important diseases, including some of the *most* important. I need only mention the prevention of malaria, yellow fever, and dengue by mosquito control, of epidemic typhus and relapsing fever by delousing methods, of plague and endemic typhus by control of rats and fleas, and of dysentery by fly eradication.

Already we have become so accustomed to the benefits from all these protective devices that we take them for granted. Only when circumstances interfere with their practice, as is often the case in war, do we realize how much we depend on them. It was dysentery, not the Turks, that defeated the British at Gallipoli, and it was dysentery and malaria, not the Japs, that defeated our own troops at Bataan.

As we go on into the future, preventive medicine will play a larger and larger part in our lives. Instead of being a secondary and relatively unimportant part in the curriculum of our medical schools, I predict that we shall have many schools devoted primarily if not exclusively to this fast-growing branch of medical science, which is still so young that it is seldom allowed to stand on its own feet. The subjects taught will be very largely biological ones, such as medical entomology, helminthology, protozoology, bacteriology, immunology, the newly developed field of aerobiology, and methods of sterilization and disinfection which are also a branch of biology, since they deal with the destruction of life.

In addition to the categories of discoveries in biology that I have already mentioned, there are other fields of biological research which are making valuable contributions to both preventive and therapeutic medicine. I have time only to mention in passing a few of the discoveries made in the year 1942.

During the past year great advances have been made in the long-neglected field of aerobiology, dealing with the distribution of pollens, fungus spores, micro-organisms, etc., through the air; new knowledge of the spread of contagion through the air has been obtained, and new methods of control worked out, using vapors and ultraviolet rays. Also within the year there have been a number of new biological methods of controlling pathogenic organisms, including discovery of an enzyme-like substance in young rats, by which tuberculosis bacilli may be shorn of the waxy coats that protect them from drugs and phagocytes, and discovery of germ-killing substances extracted from molds and from various types of soil bacteria. In the field of nutrition, evidence for the need of particular amino acids for special functions in the body have been demonstrated, and may pave the way for better control of these functions in the future. New methods have been developed for the study of the ultimate connections between nerves and muscles, which may lead to better control of paralysis and muscular diseases. Announcement has also been made of the development of germ syrups, at negligible cost, which change the bacterial life of the human intestine so that, like deer and cattle, we can not only digest the cellulose of grass, leaves, and wood, but can also synthesize our own supply of B vitamins within our own bodies. In research on cancer, which is one biological problem that is still unsolved, a number of significant advances have been made. A few more pieces have been fitted into the mosaic, bringing the final picture a little nearer to completion. In this field as in that of allergies, there is still much to be done, but there is every reason to believe that it *will* be done before very long.

Man's ingenuity has freed him from many phases of the struggle for existence to which other creatures are subject. He has gained an insuperable advantage over the wild beasts, and his inventive genius defies the attacks of climate and the elements. In his struggle against disease he has, as we have seen, made wonderful progress, although he still has far to go. There is some reason to hope that after the present global war has burned itself out we may be able to free ourselves from the one phase of the struggle for existence that man's ingenuity has steadily made more terrible, the struggle of man against man. With all the phases of the struggle for existence well in hand we may then turn to a struggle for improvement of our kind by the application of two other branches of biological science, genetics and eugenics. Within our own generation preventive medicine has grown out of therapeutic medicine; perhaps our children may live to see a still newer branch of "improvement medicine," in which endocrinology, nutritional studies, problems of aging and rejuvenescence, and eugenics will lead to greater health, more happiness, longer life, and better evolutionary prospects than have hitherto been our lot.

THE LOCUST PLAGUE¹

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THE OLDEST ENTOMOLOGICAL PROBLEM

The locust problem has confronted man since the earliest beginnings of agriculture. Biblical references to locust plagues are well known, and Joel's description of a locust invasion has never been surpassed for its dramatic picturesqueness combined with amazing accuracy of detail. The earliest known record of locusts is a picture of a locust on the wall of an Egyptian tomb of the Twelfth Dynasty, about 2400 B. C. References to locusts abound in ancient Egyptian, Hebrew, Greek, and Chinese texts, and Roman writers such as Titus, Livy, and Pliny have left us many data, some fantastic, but some of definite value. A critical examination of this information is still awaited, and it may shed new light on certain sides of the problem.

The more recent literature on the locust problem is enormous, and the number of books and papers on the subject was estimated 15 years ago at about 2,000; since then this figure has been almost doubled, owing to intensive new research. The more important contributions are published in about a dozen languages, and the task of coping with this flood is not an easy one.

WORLD-WIDE PROBLEM

It is often thought that locust plagues are restricted to a few countries and that the world at large need not be concerned about them. This view is largely due to the fact that central and northwestern Europe is now practically safe from locusts, though its southern countries, e. g., Portugal, Spain, Italy, the Balkan Peninsula, the Ukraine and the Caucasus, know their depredations only too well.

The zone where agriculture has to reckon with locusts and their lesser relatives, grasshoppers, becomes even wider in temperate Asia,

¹ Lecture delivered before the Dominions and Colonies Section, Royal Society of Arts, London, December 15, 1942, and published in the *Journal of the Royal Society of Arts*, vol. 91, No. 4631, 1943. Revised and brought up to date by the author, and here reprinted by permission of the Royal Society of Arts. The object of the present paper is to give a brief account of the locust problem and to show how recent advances in its study have made it possible to envisage its lasting solution.

where a broad belt of the fertile Siberian lands produces not only grain in abundance, but also grasshoppers which take their toll of the harvest. South of that belt, Soviet Middle Asia, producing cotton, fruit, etc., is subject to ravages of the Asiatic migratory (*Locusta migratoria migratoria*) and the Moroccan (*Doclostaurus maroccanus*) locusts. Farther east, in China, the Oriental migratory locust (*Locusta migratoria manilensis*) has repeatedly caused wholesale famines, and is actually causing untold miseries at present. The range of this locust extends to the Philippine Islands, where records of its ravages are found in the earliest Spanish chronicles, and to Borneo, Celebes, Indo-China and the Malayan peninsula.

Returning westward again, we meet the vast zone where the desert locust (*Schistocerca gregaria*) holds its sway over agriculture, which is here carried out always under precarious conditions, making its products particularly precious to the population, so that a loss of harvest amounts to a major catastrophe. It is this desert locust that has been known to man since Biblical times, and which is still as active as it was thousands of years ago. The area of its depredations is enormous, stretching from India in the east to the Atlantic coast of Africa in the west, and from Russian Middle Asia in the north to below the Equator in eastern Africa. The tropical parts of Africa also have to cope with two other kinds of locust, the African migratory (*Locusta migratoria migratorioides*) and the red (*Nomadacris septemfasciata*) locust. The latter extends its ravages to South Africa, which, in addition, has a very serious problem in the endemic brown locust (*Locustana pardalina*).

Australia, the continent where agricultural development started relatively recently, but where it has made great strides, is already paying a heavy tax to locusts and grasshoppers.

Turning to the Western Hemisphere, both the United States and Canada have to wage an almost incessant war against grasshoppers, while wide regions in Central and South America are periodically devastated by swarms of the American locust (*Schistocerca paranensis*).

Thus, none of the five continents is free from these pests, which, in fact are absent only from the forest and the tundra belts in the north, from the equatorial forests, and from the high mountains. The regions either permanently infested by them or subject to their periodical incursions include no less than 77 separate countries (fig. 1).

WHAT LOCUSTS COST THE WORLD

Beginning with the Egyptian locust plague, described in the Bible, there runs through history a tragic tale of devastations caused by locusts, followed by famines decimating populations of whole countries. Thus, in the Roman colonies of Cyrenaica and Numidia no less than

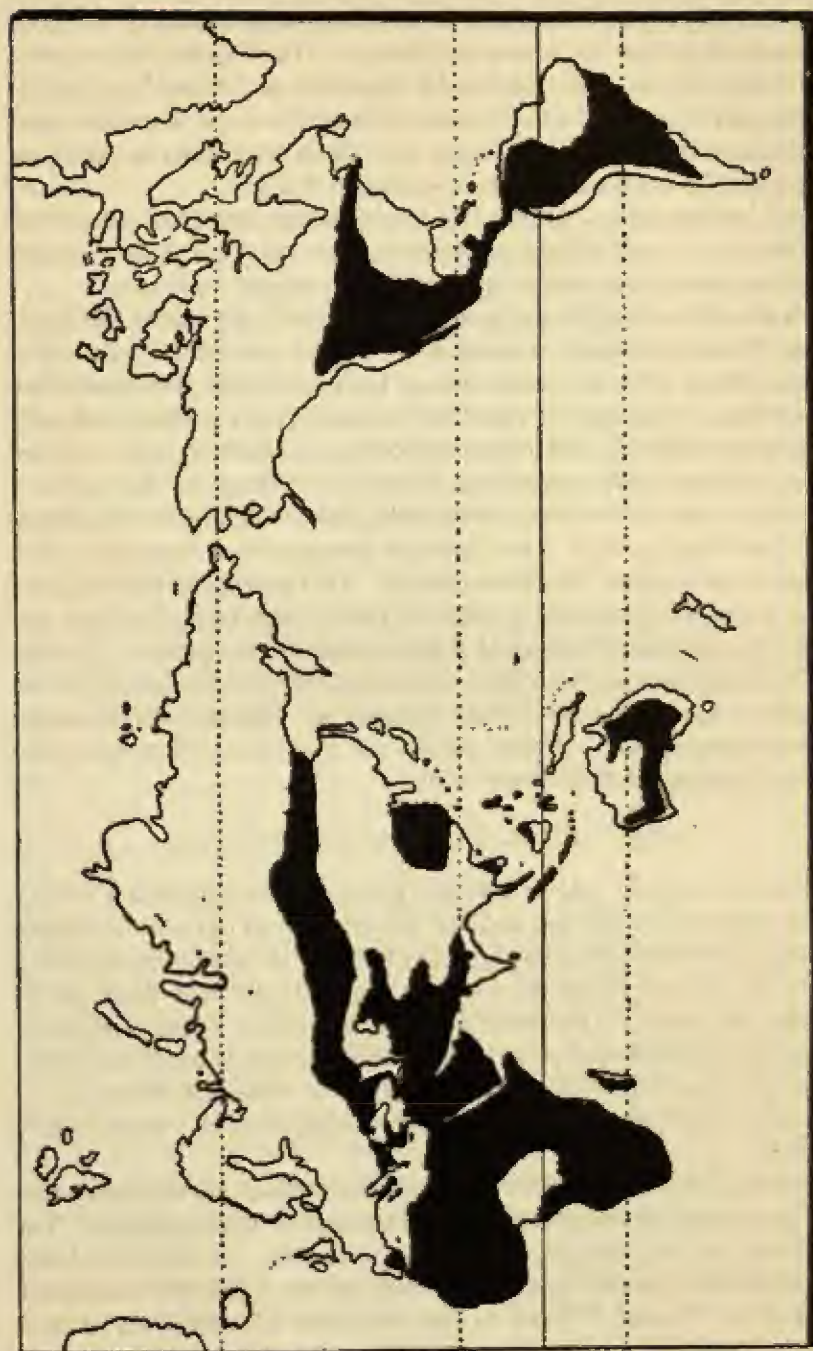


FIGURE 1.—Areas shown in black are subject to invasions by locusts and grasshoppers.

800,000 people died in the year 125 B. C. after a locust invasion. Great famines have been caused by locusts in India, China, and other countries. As recently as 1930, losses of crops estimated at nearly 1,000,000 pounds were caused by locusts in Morocco. In Nigeria, in the same year, 1,000 tons of grain had to be imported to prevent famine; in Tanganyika Territory 75 to 100 percent of native crops were destroyed in 1929, and in Kenya in the same year £200,000 had to be spent on relief from the famine caused by locusts and drought.

These are impressive figures, but it may be argued that locust invasions occur only periodically, and that a distorted picture of their economic importance is obtained by considering exceptional cases.

To assess the cost of locusts and grasshoppers to the world, the Anti-Locust Research Centre attempted to collect statistical data for a 10-year period, 1925-34, which covered both bad locust years and those free of them. Statistics of this kind were not easy to obtain, and only 49 countries (out of 77 suffering from locusts) submitted them. Nevertheless, the total was staggering, showing that crops to the value of £83,120,800 went to feed the locusts in 10 years. The losses would certainly have been greater if no defensive measures had been taken, but the latter cost another 13 million pounds. On the basis of these figures, it was not an exaggeration to estimate the average cost of locusts and grasshoppers to the world at 15 million pounds per annum. To this must be added the enormous figure of unpaid labor which is used almost everywhere for large-scale defensive measures. The data on this point are very incomplete, but the number of man-days often runs into millions in one year and in one country.

AGRICULTURAL PROGRESS AND LOCUSTS

It has been argued that locusts and grasshoppers represent a danger only in backward countries, and that the advance of agriculture should inevitably lead to their disappearance as pests. A long interval during which the United States of America were almost free from grasshoppers led some of the most eminent American entomologists to believe that agricultural progress had made a repetition of the grasshopper plagues impossible. These hopes were rudely shattered in recent years, when grasshopper outbreaks recommenced on a truly American scale.

Moreover, there are definite cases on record where direct encouragement was given to locusts by otherwise excellent developments. The Danube delta, for example, had become unsuitable for locust breeding on a large scale toward the end of the last century, but recent regulation of the river channel resulted in the emergence of new areas of land which were quickly utilized by locusts, and an area which had not produced locust swarms for many years became again a source of

danger. In northern Borneo, locusts can breed only in areas where the jungle has been cleared for cultivation and abandoned after a few seasons; such shifting cultivation there, and probably in other similar areas, is a direct cause of locust outbreaks. In western Australia, the clearing of dry forests in the interests of sheep breeding has created a type of grassland admirably suited for locusts. Overgrazing of natural pastures is largely the cause of the great, and growing, grasshopper menace in Argentina, some parts of the United States, Canada, and parts of Russia. Such facts led the Fourth International Locust Conference, held in 1936 at Cairo, to pass a resolution pointing out that the mass development of locusts and grasshoppers is furthered rather than hindered by man's activities, and that no hopes can be entertained of the problem's becoming less acute merely as a result of the general development of a country.

To this must be added the consideration that the agricultural development of new areas, e. g., in Africa, central Asia, etc., tends to increase the danger from locusts in direct proportion to the increase in the value of crops exposed to their ravages.

THE USES OF LOCUSTS

It may well be asked whether it might not be possible to find some use for the mass of organic matter represented in locust swarms, some of which have been estimated to amount to hundreds of tons. Chemical analyses show that locusts contain protein, fats, and mineral salts, which would be of value in the preparation of fertilizers and of food for cattle and poultry. From the technical point of view the idea is sound, but no industry can be based on a raw material which may be overabundant one year and nonexistent the next.

The use of locusts for food is well known, since John the Baptist lived on them, as Bedouins in Arabia still continue to do when other food is scarce. The Assyrians apparently considered locusts as food fit for kings, since a bas relief of the seventh century B. C. shows locusts being brought up to the table of Assurbanipal. Locusts are still eaten in many countries, and the Philippine Department of Agriculture has recently published a pamphlet describing 33 different ways of cooking them. Some of the recipes sound rather attractive in wartime, perhaps, because they include such ingredients as eggs, bananas, lemons, and pineapples. More plainly cooked locusts were recently described by an entomologist as "neither repulsive nor producing any pleasant sensation."

LOCUSTS AND THEIR HABITS

We have been speaking of locusts as a plague of agriculture, but in order to understand the problem, it is necessary to have a clear idea

of what locusts are and how they live. A locust is nothing but a species of grasshopper, but usually larger in size and characterized mainly by gregarious habits.

The life cycle of locusts and grasshoppers is fairly simple. The eggs are deposited by the female in the soil, in packets, or "egg-pods," each containing 30 to 100 eggs. In countries with a cold winter, eggs lie dormant throughout this season, and in spring the young locusts, or "hoppers," emerge from them onto the surface of the soil. In the Tropics, the eggs may hatch in 2 to 3 weeks, if there is rain or moisture in the soil. The difference between grasshoppers and locusts becomes apparent in the hopper stage; the former may be numerous, but each one lives independently of the others, whereas the latter congregate in dense groups, or bands. Further development consists in rapid growth, stimulated by voracious feeding on green vegetation, and in the periodic moulting which occurs 4 to 6 times before the adult insect appears; these differ from the hoppers only in size and the presence of two pairs of wings. The whole cycle occupies a year in temperate climates, but in the Tropics there may be several generations within a year.

The most striking feature in the behavior of locust hoppers is their mass movement in bands, which may cover several square miles. The relentless march of hopper bands which are not stopped by obstacles, even by water, creates an impression of a dark purpose, of a movement toward an objective, and many more or less fantastic explanations have been offered to account for it. Recent investigations have, however, definitely proved that the movement of hoppers depends very largely on temperature and occurs only on sufficiently hot days, while excessive heat again causes it to stop. The hopper movements are not caused by hunger and do not aim at finding food, since hoppers, driven by heat, often leave a fertile area and march into open desert.

When hoppers become adult and acquire wings, they soon begin to fly about in swarms. Again, a swarm does not leave an area because of lack of food, and it does not necessarily fly toward more fertile lands, but its flight is initiated, directed, and interrupted by various weather factors. Swarms may reach great size and contain fantastic numbers of individuals. Thus, a swarm in East Africa measuring 3 by 60 miles was estimated to consist of a million million locusts; and even larger swarms are on record.

The distances covered by swarm flights may be enormous. In 1693, swarms of the migratory locust from the Danube delta reached Wales, at a distance of about 1,600 miles in a straight line, though probably not in a single flight. A swarm of the desert locust was encountered in the Atlantic midway between South America and Africa, about 1,500 miles from the latter, whence it certainly came. This must have

been a single sustained flight. As will be seen later, the extent of migrations becomes even greater when the swarms of several successive generations are considered.

METHODS OF LOCUST CONTROL

It would be impossible even to enumerate here the many methods used, or recommended, for locust destruction. It is of interest, however, to point out that some of them are centuries old and are still in use. The destruction of eggs by digging was practiced in ancient China and is still widely recommended, though it is effective only in some special cases. Beating of hoppers by branches and driving them into trenches were the methods enforced by the Romans in North Africa, according to Pliny, and are still practiced in spite of being of little value and involving the use of forced labor in astronomical quantities.

In more recent times, endless new methods have been proposed and tried against locusts, such as the use of flame throwers, poison gases, bacterial diseases, steam rollers, balloon barrages, smoke screens, and even artillery. Lately, the method of poison baits has come into almost universal use. Bran, moistened with sodium arsenite solution, is scattered thinly on the ground and proves to be more attractive to locusts than green food. When the low dosage of poison, sufficient to kill locusts but not grazing animals, is strictly adhered to, there is no danger from baits, but it would obviously be an advantage to eliminate all risks. This may eventually be achieved by investigations, now in progress, with dusts which would kill locusts by contact and which could be sprayed from aircraft.

However, even some of the relatively primitive methods may be of use for destroying locusts. Indeed, it is definitely not the lack of the proper technique which hampers the solution of the problem.

ANTI-LOCUST POLICY OF THE PAST

The main stumbling block in the way of a solution of the locust problem is the fact that locust depredations do not recur annually but in cycles of several years, separated by clear intervals. When a country is invaded, no effort is spared to organize defense, which is rarely effective, since the organization usually lags behind the invasion. As soon as the immediate danger is over, the anxiety gives way to wholly unjustified hopes that perhaps the invasion will not recur, or at least not in our time, and nothing is done until the next catastrophe, which again occurs unexpectedly. It is this unfounded optimism that should be considered as the first cause of the continual recurrence of locust plagues over the centuries.

The second reason for the failure to control locusts is the isolationist policy of practically every country subject to their depredations. History provides examples of great efforts to control locusts in Algeria, South Africa, Argentina, etc., but the results were always temporary and never led to a radical solution of the locust problem, simply because it is insoluble within a single country. We have seen that swarms in their flights may, and do, cover great distances, and that they completely lack respect for any man-made boundaries. Swarms of the desert locusts, bred in India, usually migrate to Persia and Arabia, and their progeny proceed to Egypt, Palestine, and to East Africa. It is clear that control measures in any one of these countries, however effective, may only protect the standing crops of the particular season, but will have no effect on the general situation.

Sporadic attempts to approach some measure of international cooperation have not been lacking. Conventions pledging each country to control locusts within its own confines have been concluded between groups of adjoining countries (e. g., South American Republics; Iraq, Syria, and Turkey; Persia and the Soviet Union, etc.), but most of them remained paper agreements only and had no practical effect, because they all aimed at defense only, and no attempt was ever made to take concerted measures toward a lasting solution of the problem.

The most spectacular failure of such attempts to solve the locust problem by resolutions was the Rome International Conference of 1920. A convention pledging their countries to take all the necessary measures against locusts was signed by delegates of 18 countries, widely scattered over the globe. It appeared incomprehensible why Madagascar should join forces with Mexico, or Bulgaria with Uruguay, since they are threatened by entirely different species of locusts, and the course of events in one of them could not possibly have any effect on the other; and the solution of the locust problem remained unattainable as long as it was approached without sufficient scientific basis, though it was certainly right to regard the problem as an international one.

SCIENTIFIC BASIS OF A NEW POLICY

The irregular periodicity of locust invasions hampered scientific research on the problem, just as it did the organization of locust control. It was naturally difficult to persuade governments to spend money on locust research in the periods when swarms were absent, and little could be accomplished during the locust years, when all efforts were concentrated on defense. As a result, there was no answer to the question: "What happens to locusts when there are no swarms?" Since locusts matter only when they are in swarms, it appeared idle

curiosity to ask the question, but, fortunately, scientists are often attracted by "useless" problems. In this case, entomologists in Russia and in South Africa undertook investigations, and almost simultaneously, and quite independently, arrived at wholly unexpected, but closely similar conclusions. It was found that locusts in the years when they are not numerous differ from the swarm locusts in appearance and in habits. The external differences between the swarming and the solitary phases of locusts, as they came to be known, are sometimes so pronounced that the two phases were considered by specialists as belonging to different species. As regards habits, locusts of the solitary phase are typical grasshoppers, showing no inclination to form dense bands and swarms. Should, however, the numbers of locusts in a restricted area increase, so that crowding results, the locusts acquire strong gregarious tendencies. The phenomenon of phase variation in locusts has since been subjected to intensive studies, and many interesting details have been discovered, but the point of outstanding practical importance was that it opened up a possible approach to the problem of the origin of locust outbreaks.

NEW PERIOD OF INVESTIGATIONS

In 1928, a serious outbreak of the desert locust started to develop, and the British Government decided that steps should be taken to consider not only defensive measures, but also the possibility of a radical solution of the problem by ascertaining the reasons for the periodical swarming of locusts, with a view to their control. A Locust Subcommittee of the Committee of Civil Research (later transformed into the Committee on Locust Control of the Economic Advisory Council) was formed on April 29, 1929, and that date may be taken as the threshold of a new anti-locust policy. The actual work was entrusted to a special research unit, under the supervision of Sir Guy A. K. Marshall, then Director of the Imperial Institute of Entomology, and under the technical direction of the present writer. A scheme for collecting current information on locust movements and breeding in all countries of Africa and the Middle East was introduced, and several field investigators were sent out to study the problem on the spot. The organization, set up as a purely British one, rapidly attracted attention in other countries, and the First International Locust Conference at Rome in 1930 requested the British organization to act as the International Centre for Anti-Locust Research, where all the information on the subject could be centralized. The years 1930-38 witnessed a unique concentration of scientific effort on locust investigations. Parties of British, French, Belgian, South African, Indian, and Egyptian experts systematically explored one area after another; spending months in the regions which are rightly

regarded as most inhospitable; establishing temporary field laboratories; and gradually disentangling the many threads of the great problem. Nor was this extensive work uncoordinated, since practically every year the experts and other representatives of the countries involved came together for a conference, to pool the results and to plan further campaigns. The accumulation of information on locusts at the International Centre, in the meantime, went on, with a steady improvement in the unified reporting system, which by now covered the entire continent of Africa and a substantial portion of Asia. All countries in that immense region submitted monthly reports on the locust situation. These reports were critically examined, summarized and mapped, so that all developments in the situation could be followed step by step.

A feature of this international effort was its development without the signing of formal conventions and on a basis of direct collaboration between experts of many nations, with the ready support of their governments.

The results of this teamwork, which is certainly unique in entomological history, have justified the effort. At the outset of the investigations, practically nothing was known on the distribution of the different species of locusts in Africa, on their seasonal cycle and migrations, and particularly, on the origin and the course of their periodical outbreaks. After 8 years of intensive work, a clear picture of the whole problem became available, which has made it possible to formulate an entirely new anti-locust policy, aiming at a radical solution of the locust problem.

NEW ANTI-LOCUST POLICY

The investigations just outlined have provided abundant evidence that the periodicity of locust outbreaks is closely connected with the periodical transformation of the harmless solitary phase into the dangerous gregarious one. Such a confirmation of a scientific theory may appear of no importance except to experts, but actually the theory has supplied the key to the whole problem. It was proved that the transformation into the gregarious phase can happen, in the case of each locust species, only in certain relatively restricted areas with peculiar natural conditions, and it is only in these outbreak areas that the first swarms can be formed. In the case of the African migratory locust it was shown that a few small swarms arising about 1928 in a restricted area on the middle Niger in the French Sudan were the cause of an invasion which in 5 years swept over the greater part of the African continent (fig. 2). The outbreak areas of the red locust have been located in Tanganyika Territory and in Northern Rhodesia. With regard to the desert locust, it was found that its

swarms can arise from the scattered locusts of the solitary phase on the coasts of the Red Sea, in Baluchistan, and in Mauretania.

The fact that the great locust invasions are due to very small beginnings has important implications, for once the original outbreak

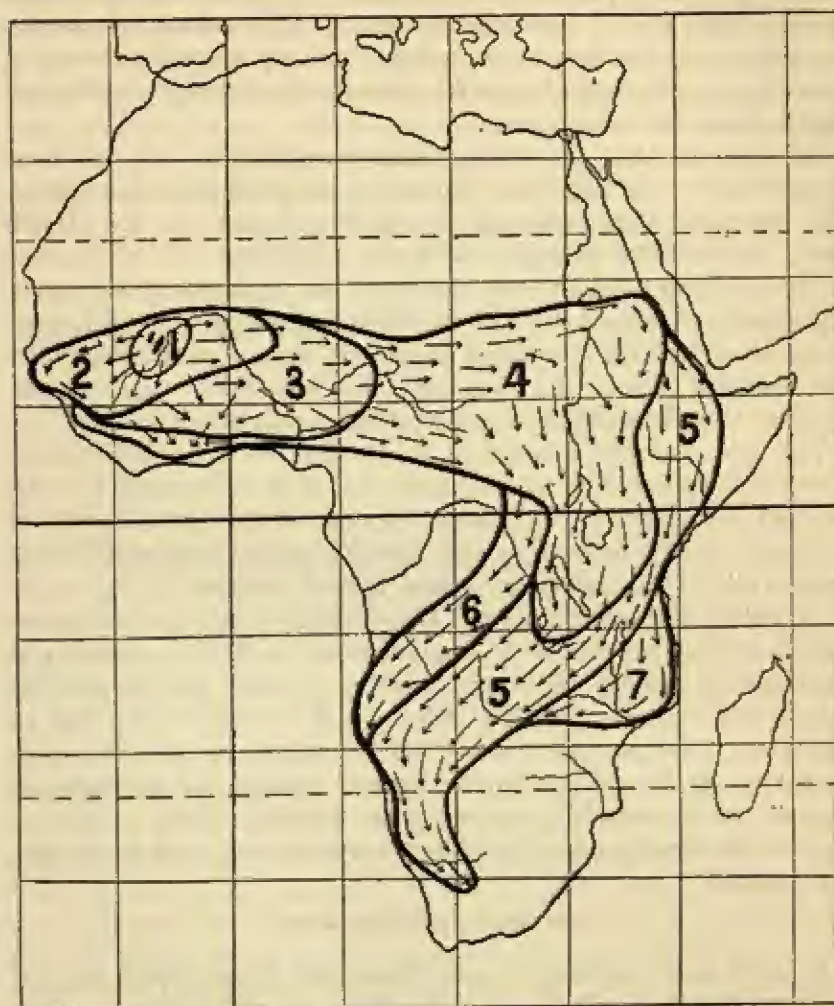


FIGURE 2.—Map of Africa showing the spread of swarms of the migratory locust (*Locusta migratoria migratorioides* R. & F.) during the last outbreak. The outbreak commenced in 1928 in the two centers on the Middle Niger shown in black and spread in the same year over the area numbered 1. The areas gradually invaded during each of the following years are numbered consecutively. Generally, two generations were produced each year. The arrows represent only the main lines of migration, smaller seasonal movements not being shown.

areas are known, they can be put under permanent observation and any tendency on the part of the solitary locusts to form incipient

swarms can be suppressed before they have had a chance to spread elsewhere. The new policy of locust control aims, therefore, at preventing the outbreaks instead of allowing them to develop into invasions and then trying to devise desperate defense measures.

This policy of prevention of locust outbreaks is clearly more rational than the old defensive policy. It is also more economical, requiring a regular annual expenditure of only a small fraction of the average annual cost of the defensive measures, apart from eliminating the losses due to invasions.

By the year 1938, the international investigations had advanced so well that it was possible to formulate practical plans for dealing with the three main locust species affecting Africa and the Middle East. At the Fifth International Locust Conference held at Brussels in 1938, definite schemes were elaborated for establishing permanent organizations for the control of the desert, migratory, and red locusts. These plans, naturally, required further discussions of administrative and financial details, and these extended into 1939, when the outbreak of the war made the locust problem appear insignificant.

Very soon, however, it became apparent that the war would demand a maximum production of foodstuffs and that crops must be safeguarded from locusts. Unfortunately, most of the outbreak areas of the desert locust were near, or very close to, the war zone, and the outbreak areas of the migratory locust became inaccessible to outside experts after the fall of France. There remained only the red locust, and the scheme for its control, supported by the British colonies and protectorates in East Africa, by Southern Rhodesia and the Belgian Congo, was launched in 1940. Recently, it became known that an organization for preventive control of the migratory locust has been established by French authorities without waiting for international support, which must be given as soon as possible. Thus, in spite of the war, the foundation stone of permanent international locust control was laid.

LOCUSTS AND THE WAR

It was a most unfortunate coincidence that, after a quiet interval of several years, the desert locust exhibited signs of renewed swarming just as the war broke out and the first swarms had a chance to escape observation and destruction. By the time the areas in question had become more accessible, the swarms were not numerous, but sufficiently widespread to necessitate an urgent campaign for the protection of crops throughout the Middle East and East Africa. From the point of view of organization, war conditions proved to be, paradoxically, more favorable for an anti-locust campaign than normal times. The importance of safeguarding vital food supplies, both for the troops and the population, became a powerful factor in

obtaining the willing cooperation of all concerned. This made it possible, for the first time in the history of locust control, to organize not a dozen small national campaigns designed mainly for defense, but a unified campaign embracing the whole affected area and assuming the character of offensive operations. These operations are based on a knowledge of the seasonal movements of swarms, which has been accumulated in past years and which makes it possible to forecast the course of events with considerable accuracy. It is a matter of justifiable pride for the Anti-Locust Centre that in the present invasion every country has received a timely warning, and that these warnings have proved to be correct.

THE INTERNATIONAL ANTI-LOCUST CAMPAIGN

Seasonal movements of the desert locust cover an enormous region. Swarms produced during the summer monsoon rains in India fly in the autumn to southern Persia and Arabia; the latter country receives about the same time the swarms bred on summer rains in Africa. The winter and spring rains in Arabia and southern Persia enable these locusts to multiply and the new swarms produced in these countries move during the spring into Sinai, Egypt, Palestine, Syria, Iraq, Central Persia, Afghanistan, and India, sometimes reaching as far north as Turkey and Soviet Middle Asia, breeding wherever they meet rains. The Red Sea, Gulf of Aden, and even the Arabian Sea are liable to be crossed by swarms migrating between Africa, Arabia, Persia, and India. Many swarms from Arabia cross to the Sudan, Eritrea, and Ethiopia, where they are able to breed again on summer rains. In the Somalilands, Ethiopia, and East Africa, the seasons are somewhat different, but the principle remains the same, since locust swarms always evacuate a region which becomes too dry and migrate to a rainy one. As a result, the whole enormous region stretching from East Africa to India has to be regarded as a single interconnected migration area. Obviously, the general strategy of the anti-locust campaign had to be based on the knowledge where and when the enemy could be best attacked. An essential principle of this strategy was to evolve a single plan of the campaign, with a view to exterminating locust swarms wherever this can be done with the maximum effect.

In planning the campaign, it was essential to make full use of the fact that in many of the affected countries there existed efficient local entomological organizations. Such organizations in India, Anglo-Egyptian Sudan, and the British East African colonies could be relied upon to organize locust control in their own territories, within the framework of the general campaign. Some of them went further, and generously offered their assistance to the surrounding

territories. Thus, the Sudan-supplied personnel and bait for Arabia; India sent a trained staff to help in Persia and Oman; Kenya has undertaken to supply bait to the territories of the former Italian East Africa, etc. In Persia where local personnel was competent to deal with the situation, the extent of the operations required was too great for the local resources, and British, Indian, and Soviet Governments came to their assistance by providing additional personnel, motor transport, bait, etc.

The chief problem, however, remained that of Arabia, a vast sub-continent devoid of communications, with a sparse population, which has little interest in locusts as agriculture is practically nonexistent. On the other hand, this is one of the most important locust-producing areas. Fortunately, most of the peninsula is under the rule of King Ibn Saud who is keenly interested in the development of his country and he not only agreed to admit anti-locust missions but offered ready assistance in their work. Small motorized anti-locust missions were sent to various parts of Saudi Arabia and Oman in 1942-43, mainly for the purposes of studying the conditions and acquiring experience in desert warfare against locusts. The next winter (1943-44) it became possible with the assistance of civil and military authorities to send into Arabia several well-equipped missions, comprising over 350 motor vehicles and nearly 1,000 men. These missions were distributed over all the most important locust-breeding areas and have accomplished a magnificent piece of work in spite of many and various difficulties. Most of the personnel were British, but it included also Americans, Egyptians, Indians, Palestinians, and Sudanese locust officers and technical assistants. The whole anti-locust army was technically directed by the Chief Locust Officer (R. C. Maxwell-Darling, later succeeded as Senior Locust Officer in Arabia by D. Vesey-Fitzgerald), and various detachments kept in touch by wireless. Many thousands of square miles of territory, some of it never before visited by Europeans, have been effectively cleared (by poison bait) of locusts, which were killed in quantities defying all estimation. Apart from the immediate achievement in reducing locust hordes, which would have invaded the adjoining fertile countries, the Arabian campaign had a great propaganda value, showing the population that locusts, which used to be regarded as Allah's visitation, can be killed and crops saved from them. These crops may be few and far between, but this makes their local value even greater than it would have been elsewhere. The campaign has also demonstrated the sincerity of purpose of the United Nations in sending the anti-locust missions. For those who conceived the idea of the Arabian campaign and who participated in planning and in carrying it out, it was an encouragement to see that, as it was hoped, locusts can be beaten on their own ground.

Anti-locust campaigns on a similar scale had to be organized also in East Africa, where military authorities rendered most valuable help with regard to transport and personnel, while the Royal Air Force was everywhere playing its part, helping with communications and transport. In order to coordinate operations in all British territories and the occupied Italian ones, an East African Anti-Locust Directorate was established at Nairobi. In Kenya efforts on a particularly great scale have been made, with the result that the agricultural production of the country, which has greatly increased during the war, has not suffered to any serious extent. In the past, locust invasions in East Africa often entailed wholesale destruction of crops and famine resulted.

A gallant fight has been put up by India, where great difficulties had to be overcome in order to centralize the direction of the campaign, since locusts were supposed to be the responsibility of each separate provincial government, not all of which were equally alive to the danger. However, good progress has been made and in 1943 a great, if temporary, victory over locusts was won in India, which by the end of the year was clear of swarms, but became reinvaded from the west in 1944 when again a successful campaign was carried out. This reinvansion served to underline the fact that no country can hope to achieve a lasting success by its own efforts alone, but all have to work together.

Ethiopia presented a particularly difficult problem. As in the case of Arabia, many parts of Ethiopia serve for the production of locust swarms and it was impossible to expect that they would be controlled locally. Moreover, previous knowledge of Ethiopia in relation to the locust problem was extremely meager. Therefore, a special mission was sent to Ethiopia in 1942 with a view to investigate the situation, to organize regular locust information service, and to work toward making the authorities locust-conscious. By 1944, it was possible to report excellent progress in all these directions, but there remained still large areas where locusts continued to breed but where it was impossible to organize their effective control. These areas of Ethiopia, as well as Yemen in Arabia, so far remain beyond the general plan of the campaign, but in both countries there are hopeful signs of improvement.

The organization of a series of campaigns of such magnitude would have been impossible without the ready cooperation of all governments concerned, and of the many civilian, military, and air authorities of the Allied nations. Special credit is due to the Middle East Supply Centre, an Anglo-American regional economic organization based in Cairo, with ramifications over the whole of the Middle East. That Centre, advised by the Chief Locust Officer (R. C. Maxwell-Darling, succeeded by O. B. Lean), has undertaken to shoulder the heavy burden of organizing and administering the campaigns in Arabia and

Persia, and such successes as have been achieved are largely due to the efficiency of the machinery which had to translate into action the plans prepared by experts.

The invasion area of the desert locust, however, is not restricted to East Africa and the adjoining parts of Asia, but extends across the French West and North African territories. Here the organization of control is in the hands of French authorities, and the Allied Governments are only rendering assistance by supplies of poison. French experts and the administration are faced with enormous difficulties in organizing their anti-locust campaigns, but their efforts are meeting with considerable success. Great progress in the anti-locust organization was marked by the establishment in 1943 of the Office National Antiacridien at Algiers. This office, directed by the outstanding locust expert, Dr. B. N. Zolotarevsky, aims at coordinating anti-locust measures throughout the French African territories. A continuous working contact is maintained with the Anti-Locust Research Centre in London, and in this way the unity of the general plan is ensured.

The great series of anti-locust campaigns just outlined is far from being over, and it is too early to claim their success. Nevertheless, it is significant that, with the invasion in its fourth year, no serious losses of crops occurred anywhere, in sharp contrast to what happened in the past invasions by the desert locust. Great efforts were needed to achieve this result, but their cost must be regarded in relation to the losses that appeared unavoidable. It should be clearly understood, however, that this success is only a temporary one, and any relaxation of effort would lead to a disaster. In fact, the year 1944-45 may see the peak of the present invasion which will probably continue for 2 to 3 years more, and the campaigns will have to go on until the danger is overcome. The need for protecting food production in Africa and the Middle East was particularly urgent during the war, but it would be a poor introduction to the postwar world if a famine were allowed to develop on the conclusion of hostilities.

THE CODLING MOTH

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(With 6 plates)

INTRODUCTION

The codling moth, *Carpocapsa pomonella* L., is a conspicuous example of an insect species that has been able to maintain itself as a destructive pest of apple orchards for more than a hundred years in spite of the continuous development and improvement of control practices. Forty or more investigators employed by the United States Department of Agriculture, State agricultural experiment stations and other State agencies, and insecticide companies, are now devoting all or a considerable part of their time to this problem, and progress is constantly being made in the development of control measures. The literature has become so voluminous that no one person has ever reviewed all of it. Yet with all of this progress the insect continues to cause serious losses to apple growers. Since similar trends have been exhibited by certain other insects, a review of the evolution of control measures for the codling moth, and the conditions that have permitted the insect species to maintain itself in spite of these control measures, may be of interest to students of insect control problems.

BIOLOGY OF THE CODLING MOTH

For the benefit of readers who are not well acquainted with the codling moth, a brief summary of its seasonal history will be given: The codling moth passes the winter as full-grown larvae in cocoons, in crevices in the bark of the tree, under loose flakes of bark, in debris on the ground, and in similar places (pl. 1, fig. 1). In early spring, as the buds begin to push out, the insect changes to the pupa (pl. 1, fig. 1), or stage in which the transformation from larva to adult moth takes place (pl. 1, fig. 2). The first moths appear about the time the apple trees come into bloom, and shortly begin to lay their white, scalelike eggs (pl. 2, fig. 1) on the leaves, chiefly around a fruit spur. Later many of the eggs are placed directly on the fruit. The newly

hatched larvae make their way to the fruit, unless the eggs were already there, chew their way in, and feed on the pulp and seeds until mature (pl. 2, fig. 2). During the first part of the season many of the worms enter through the calyx, or blossom end of the fruit; later most of them enter the fruit through the side. The minimum time required for a complete life cycle under the most favorable conditions is approximately 37 days. The number of generations in a season ranges from one, with a negligible fraction of a second, in the more northern apple-growing sections, to three nearly full generations and a part of a fourth, in the more southern localities in which apples are grown. In favorable seasons in such localities, the worm population in late summer reaches tremendous numbers. In unsprayed orchards there may be five or more worms in nearly every apple, and the crop is completely riddled; in many reasonably well-sprayed orchards losses of 20 to 30 percent are not uncommon. Although a few growers may succeed, worm control is an uphill fight under such conditions, and in certain localities in which such conditions exist, apple production has undergone a serious decline.

CONTROL BY ORCHARD SANITATION

Until late in the last century, partial control of the codling moth was accomplished by various practices which are often referred to as "orchard sanitation," including the trapping of the mature worms under bands. The early writers recommended the removal of loose bark from the tree trunks, the destruction of rough ground debris, and the removal of dead wood from the tree, in order to destroy the insects in their hibernating quarters and to eliminate their favored cocooning places. The removal and destruction of infested fruit, the screening of packing sheds, and similar measures, were also suggested.

For the purpose of trapping the worms, a number of ingenious types of bands and other traps were developed during the nineteenth century. Banding was first suggested about the middle of the century (Burrelle, 1840). One of the bands most widely used for a time was a hay-rope band (Trimble, 1865) (pl. 3). After a few years, however, this type of band gave way to materials more convenient to use, such as heavy wrapping paper, burlap, canvas, or flannel cloth. Some growers who used the cloth bands killed the worms trapped in them by running the bands through a clothes wringer, mounted on a wheelbarrow for convenience in operating it and moving it from tree to tree in the orchard. Then there was the Wier shingle trap which consisted of three shingles placed on the trunk of the tree, and held just far enough apart to furnish an attractive cocooning place. The worms were killed by rubbing one shingle against another, or by giving the whole device a sharp blow with a hammer.

With the advent of spraying, the control measures just outlined—banding, the scraping of loose bark from the trees, destruction of debris, and similar practices—became supplementary or were discontinued entirely. About 15 years ago, Siegler and associates (1927) devised a chemically treated band which automatically kills the worms that enter it. Such bands are now used by many growers. A revival of the various sanitary measures took place from 1926 to 1935, when difficulties with spray residues were the most acute. The use of such measures was, however, still looked on as secondary and supplementary to spraying.

The predominant development in the codling moth problem has been the adoption and evolution of spraying.

EVOLUTION OF CONTROL BY SPRAYING

In 1878 the control of the codling moth was completely changed by the discovery made by two New York State growers that the recently developed use of Paris green against canker worms was also giving control of the codling moth. This was reported the following winter (Woodward, 1879), and in 1880 there were conducted in Michigan the first official experiments with an arsenical, known as London purple, for codling moth control (Cook, 1880). The favorable results obtained stimulated extensive experiments elsewhere with both Paris green and London purple. Early in the twentieth century these materials gave way to lead arsenate, which in a short time became the standard material for codling moth control. Lead arsenate was first available as a paste, often prepared by the grower himself from sodium arsenate and lead acetate or lead nitrate. Soon, however, lead arsenate became commercially available in a powdered form, which rapidly displaced the paste material, because of greater convenience of handling. The effectiveness of lead arsenate has been further increased by the use of various accessory materials, such as fish oil or mineral oil emulsion. With certain accessory materials the lead arsenate continues to build up on the fruit and foliage with prolonged spraying, instead of leaving the tree with the run-off.

The spray programs followed by growers have also undergone a marked evolution. At first many growers obtained satisfactory control with a single spray, applied just after the petals fell. After a few years, however, the need for more spray applications during the season became evident, and now many growers put on 8 to 10 or even more applications of spray for codling moth control. Many of the State colleges or experiment stations regularly furnish the growers with current information on codling moth development during the season, to aid them in the timing of spray applications. The use of traps containing baits of fermenting solutions of low-grade sugars or

syrups, often with added aromatic chemicals, although not accomplishing their original purpose of direct control, have been found valuable aids to the timing of spray applications, by giving information on moth activity and abundance in the orchard.

SPRAY-RESIDUE PROBLEM

In the earliest official test of arsenicals (Cook, 1880) the question of the effect of the material on the consumer was considered. On the basis of analyses which were made at that time, the conclusion was reached that the quantity of poison that could be carried over to harvest as a result of the spraying was insignificant. With the type of spraying that was done in the early days this was probably a correct conclusion. However, as the number of spray applications increased, along with increases in the strength of the spray mixture, and in the number of gallons applied per tree, the quantities of lead and arsenic on the fruit at harvest constantly increased. The question of dangerous residues was raised from time to time but it was usually dismissed with a statement that it would be necessary to consume an impossibly great quantity of the product at one sitting to obtain an injurious dose. During all this period the acute toxicity was the only consideration, but in the early 1920's there developed a realization that the use of lead arsenate sprays had increased to a point where American fruit was carrying quantities of residue actually or potentially dangerous to human health from a cumulative standpoint. The situation was crystallized in 1925, when British health authorities rejected shipments of American apples because of excessive arsenical residues. This episode was followed by appropriate action by the United States Department of Agriculture in carrying out its responsibility for the enforcement of the Food and Drugs Act. This action caused consternation in the apple industry, but fortunately effective washing methods and machinery were promptly developed for removing the residue before the fruit is marketed, which has permitted the continued employment of lead arsenate until other less objectionable insecticides or other methods of control are developed.

SEARCH FOR NEW INSECTICIDES

The difficulties with spray residues and with worm control in some localities have led to an intensive search for better and less objectionable insecticides. This search has already proved productive. Cryolite is effective in the Pacific Northwest, although it is undependable elsewhere, and its use involves something of a spray residue problem and in many cases washing the fruit is necessary. Nicotine bentonite has been found more effective than lead arsenate in certain parts of the Middle West and is used to a considerable extent there

and elsewhere. Nicotine sulfate with oil is likewise used in some localities. Phenothiazine, when very finely ground, has given outstanding control in the Northwest, but has not come into commercial use because of the unfavorable effects on the fruit and on orchard workmen, and because of cost. The most recently discovered material is DDT (2,2-bis(parachlorophenyl)-1,1,1-trichloroethane) which may outstrip all the others, although a final decision on its ultimate usefulness can be made only after more extensive tests have indicated its effects on the consumer, on orchard workers, on fruit trees, and on the beneficial insects that aid greatly in keeping orchard pests within bounds or that provide for the pollination of the fruit.

DEVELOPMENT OF SPRAY MACHINERY

Along with the evolution of materials and programs for codling moth control has been the development of spray machinery for the application of the insecticides. The original hand-operated, back-breaking barrel pumps soon gave way to crude power-operated outfits (pls. 4, 5). Power spraying equipment has been steadily improved, coincident with the development of the automobile and airplane. The grower now has his choice of stationary sprayers, which pump the spray mixtures from a central plant through overhead or underground pipes to outlets placed at suitable intervals through the orchard, standard portable rigs (pl. 6, fig. 1), or the recently developed air-blast type of sprayer (pl. 6, fig. 2), which delivers the spray by means of the blast from a propeller similar to those used in airplanes. Present-day standard spray outfits give pressures up to 700 or 800 pounds per square inch and will deliver 20 to 50 gallons per minute or more. A number of men can spray at the same time from the larger-capacity stationary sprayers.

CONTINUED DIFFICULTIES IN CONTROL

With the development of improved spray materials and mixtures, high-power, large-capacity spray machinery, and carefully worked-out spray programs, which all together result in spray deposits on fruit and foliage that would have been unbelievable 50 years ago, it would be natural to expect a corresponding improvement in codling moth control. Actually, however, nothing of the kind has occurred. Although in most orchards the growers are obtaining a reasonable degree of control, there is no indication that the worms are any less abundant or destructive than they were 50 years ago. In fact, in some areas the growers are having more difficulty than ever before in controlling the worms. In such areas, in which conditions favor the insect, 20 or 30 percent of the apples are often wormy at harvest time, in spite of the making of 8 to 10 spray applications during the season, and the

use of supplementary control measures. It is therefore evident that the codling moth, instead of being a more or less fixed quantity, and subject to reduction in numbers, as control methods have been improved, has undergone an adaptation or evolution that has permitted the insect to hold its own or even to increase in numbers in spite of man's efforts.

CHANGES IN CONDITIONS

First, the standards by which control is judged have been modified from time to time. With the trend toward the concentration of commercial apple production in areas remote from markets, only high-grade fruit is worth the cost of shipping thousands of miles, and in such areas moderately injured fruit, which in localities near the consuming centers might bring fair prices in local markets, is now a total loss. Also, the American public demands a higher standard of perfection in its fruit products than ever before. This all means that our standard of satisfactory control is much higher than it was 50 years ago.

Many of the practices adopted by fruit growers have given advantages to the codling moth. Apple production has passed from small, isolated farm orchards to more intensive production in limited areas. In these newer areas conditions are sometimes especially favorable for the apple crop, but in other cases there has been extensive promotion of apple culture outside the range within which the apple would normally thrive. In either case, this trend has been an important factor in favor of the worms. With an abundance of its favored food available in virtually continuous, extensive acreage, with improved varieties and cultural methods that have to a certain extent eliminated the biennial bearing habit that characterized many of the older apple varieties, a factor that automatically held the codling moth population at a low point, it is not surprising that the present-day grower has to deal with a more numerous population. As these areas have come into full bearing, the mature trees have often reached such size that spray coverage has been poor.

The benefits derived from the extensive use of insecticides have undoubtedly been offset to some extent by their unfavorable effect on the abundance and activities of parasites and predators of the codling moth. Evidence has been obtained in New York State (Cox, 1932; Collins, 1934) that one of the most important larval parasites of the codling moth, namely *Ascogaster quadridentatus* Wesm., is adversely affected by lead arsenate and that in sprayed orchards the percentage of parasitization is less than half of that existing in unsprayed orchards. It is not at all improbable that the effectiveness of other parasites and perhaps predators is also very much reduced by the continued use of lead arsenate. This factor may have been an important one in permitting

codling moth populations to get out of hand in certain localities. Closely related is the effect of other present-day orchard practices on the parasite population. It may well be that the intensive clean-culture or cover-crop systems followed in many modern orchards may have eliminated many of the other hosts of the common parasites of the codling moth, thus causing the balance to swing in favor of the codling moth.

ADAPTATION ON THE PART OF THE CODLING MOTH

The factors just outlined, however, are not sufficient to explain the marked increases that have developed in the ability of the codling moth to thrive in the presence of heavy deposits of lead arsenate. Some change seems to be taking place in the insect itself that is modifying its ability to enter fruit in spite of the presence of a poison.

The most extensive study that has thrown light on this problem has been carried on by W. S. Hough, of the Winchester field laboratory of the Virginia Agricultural Experiment Station. His earliest work (Hough, 1929 and 1934) included a comparison of codling moth stocks from near Grand Junction, Colo., where the insect had become notoriously difficult to control, with stocks from Virginia, where control was much easier. Dr. Hough showed that newly hatched codling moth larvae from Colorado stock were able successfully to enter fruit heavily sprayed with lead arsenate to the extent of 15 to 40 percent or more, whereas the proportion of native Virginia larvae entering similarly sprayed apples was usually less than 5 percent. Further, this difference persisted through 14 or more generations reared in the insectary under Virginia conditions. Crosses gave intermediate results. Hough later (1943) found that Virginia larvae from stocks from orchards having a history of intensive spray programs were able to enter sprayed fruit in much greater proportion than those from unsprayed or poorly sprayed orchards. Strains from various Virginia orchards fed through successive generations in the insectary on sprayed fruit became differentiated from the parent strains, and showed increased ability to enter sprayed fruit. Steiner and associates (1944) have shown similar wide differences in codling moth stocks from different orchards in the Ohio Valley with respect to their ability to enter sprayed fruit. Both of these investigators have found that this condition is not restricted to lead arsenate, but that differences, although not always so wide, exist with respect to other insecticides, including nicotine bentonite and cryolite. Hough has reached the conclusion that these differences are due to differences in general vigor, but Steiner's observations have suggested that they may result from differences in habits.

Both of these workers believe that the different strains have been segregated by the elimination of those larvae that have the least ability to enter sprayed fruit, rather than that individuals have be-

come immune or resistant to specific compounds and that such immunity or resistance has been transmitted to their offspring.

Increased ability to survive in spite of insecticide treatment has been exhibited by a number of different insects, including the California red scale, *Aonidiella aurantii* (Mask.), certain strains of which are much more resistant than others to fumigation with hydrocyanic acid. The tendency toward the segregation of races within economic species has been thoroughly reviewed by Smith (1941).

The evidence just cited indicates that, instead of remaining constant and static while the evolution of control measures was going on, the codling moth as a species has undergone considerable adaptation or evolution on its own account in the direction of greater ability to survive in the presence of insecticides. The segregation of resistant strains, together with certain practices on the part of the fruit industry, have permitted the insect to maintain its position as the most seriously destructive pest of the apple in spite of the development of control by insecticides to a high degree of efficiency, at least in the application and maintenance of heavy deposits of insecticides during the periods when needed. The codling moth is only one of the several insect pests known to have undergone development in this general direction, and many other insects may be developing in a similar way, but at a slower rate. It is evident that ultimately insecticides or other control measures that are less selective in their action will have to be used for the control of the codling moth, or perhaps the problem can be solved by occasional changes from one insecticide to another that is selective in a different way. Whatever the eventual solution of the problems that have grown out of the evolution undergone by the codling moth, the entomologists will undoubtedly be able to meet this challenge to their ingenuity and resourcefulness, and any solution of this particular problem may point the way to means of meeting similar problems with other insect pests as such problems arise.

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1. HIBERNATING CODLING MOTH LARVA AND SPRING PUPA IN COCOONS UNDER-
NEATH LOOSE BARK OF APPLE TREE.
(X2.)



2. CODLING MOTH ADULT.
(X3.)



1. EGGS AND NEWLY HATCHED LARVA.

(X30.)

(From drawing by R. E. Snodgrass.)



2. FULL-GROWN LARVA IN SMALL APPLE IN WHICH IT HAD FED.

(X2.)

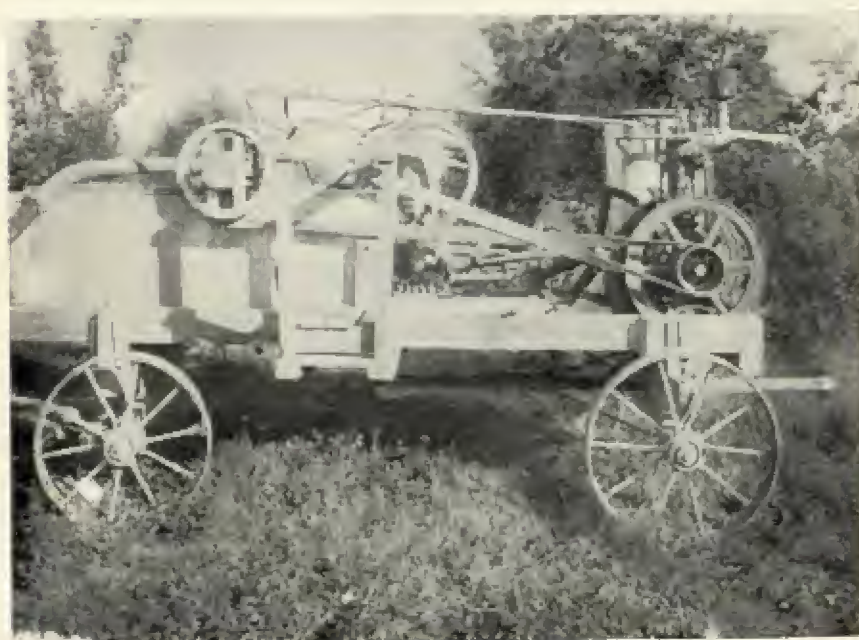


TRIMBLE HAY BAND, A TRAP FOR FULL-GROWN LARVAE, USED ABOUT 1865 AS A MEANS OF PARTIALLY CONTROLLING THE CODLING MOTH.

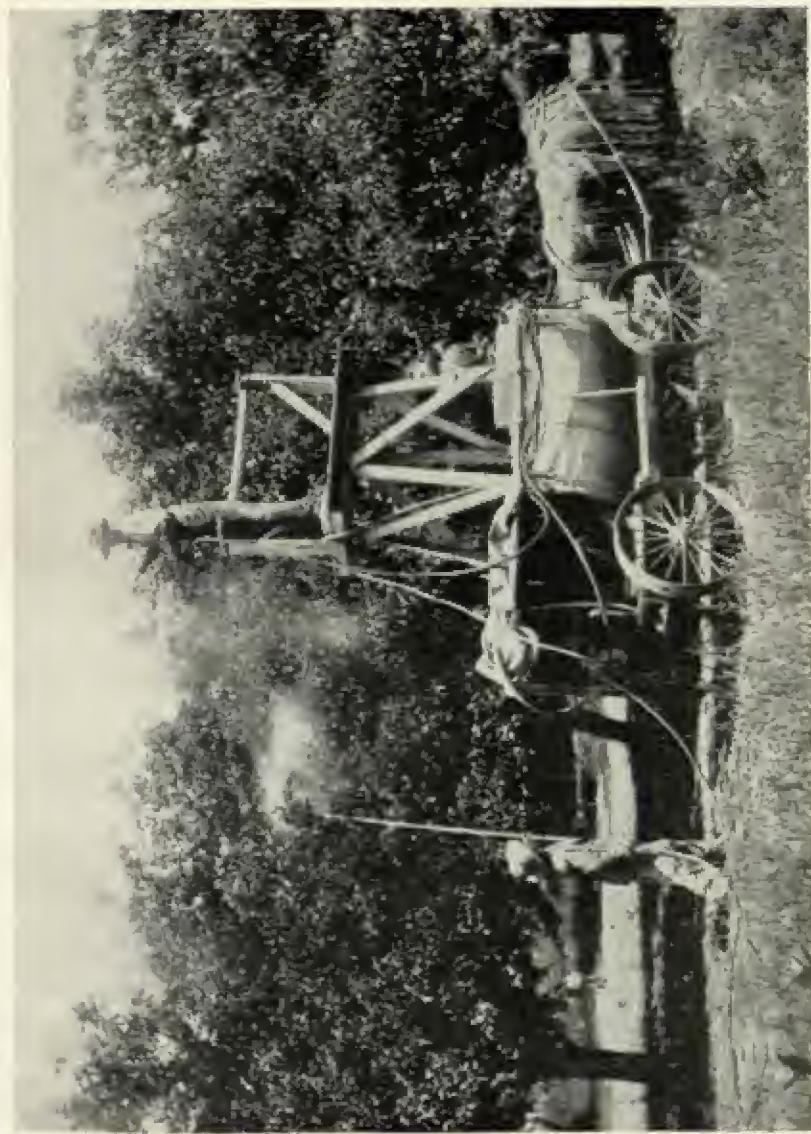


1. A HAND-OPERATED BARREL-PUMP SPRAYER.

Extensively used for codling moth control late in the nineteenth century; still used to a limited extent in small orchards.



2. PRIMITIVE TYPE OF GASOLINE POWER SPRAYER, USED IN THE EARLY TWENTIETH CENTURY FOR CODLING MOTH CONTROL.



POWER SPRAYER IN USE FROM ABOUT 1910 TO 1925

This loop, neck-turning rods were in time replaced by shorter "guns," and later by the hopper type of nozzle arrangement. (See pl. 6, fig. 1.)



1. MODERN TYPE OF PORTABLE POWER SPRAYER.

Because of wartime manpower shortage, the tractor driver is also applying spray to the lower parts of the tree by the use of a flexible broom type of nozzle arrangement. Ordinarily the spraying of the lower parts of the tree would be done by a man on the ground, who would apply the material from a number of directions. (Photograph taken in 1944 by L. F. Steiner.)



2. AIR-BLAST TYPE OF SPRAYER.

The liquid is pumped at low pressure into an air blast produced by an airplane propeller. This outfit permits the application of the spray in a very speedy manner and with minimum use of manpower. (Photograph by L. F. Steiner.)

GRASSLAND AND FARMLAND AS FACTORS IN THE CYCLICAL DEVELOPMENT OF EURASIAN HISTORY¹

By J. RUSSELL SMITH

[With 1 plate]

This paper might be called a study of equipment eras—or the interacting influences of equipment and culture in certain environments.

Man is a tool-using animal, and there is a tendency to confuse the results of mental or personal qualities and the results of the equipment that we may have at hand. Consider for a moment a group of European primitives, so-called, who left cultural and skeletal remains in caves of France some 20,000 years ago. Anthropologists have named them Cromagnon. If they were living today most of us would doubtless call them savages, regard them as inferior beings. Sir Arthur Keith tells us that the Cromagnons had larger brain pans than we have. But we of this generation have inherited agriculture with its crops and beasts, also engines and machines, transport and buildings, and books, the master tool, the mother of tools.

It is easy for us in our inherited cultural riches to lose sight of the scanty cultural inheritance of Cromagnon man. He and his parents were living in the collector stage of economics. He plucked his living from the natural environment with the aid of his fingers, toes, and teeth, and with equipment of wood, fire, flint, shells, bone, sinew, and skins—Stone Age we call it. He ate everything that was digestible—beast, birds, fish, reptile, and insect, seed, leaf, stem, and root, and sometimes the neighbors, but that was usually ceremonial. He probably lived a life filled with terrors and what we would regard as impossible hardship.

It is one of the greatest achievements in human history that Stone Age man made some sort of living in every continent except Antarctica. Archeologists and anthropologists trace Stone Age man from shores of the Arctic Sea in Greenland to the chill and reeking wetness of Tierra del Fuego; from Alaska to Newfoundland; from Gibraltar to Kamchatka; from the Siberian Tundra to South Africa, Tasmania, and the far islands of the Pacific. Stone Age man made a living

¹ Reprinted by permission from *Annals of the Association of American Geographers*, vol. 33, No. 3, September 1943.

in every important type of environment except the glacial ice cap; he was even found living cheerfully at the very foot of the ice cliffs in Greenland.

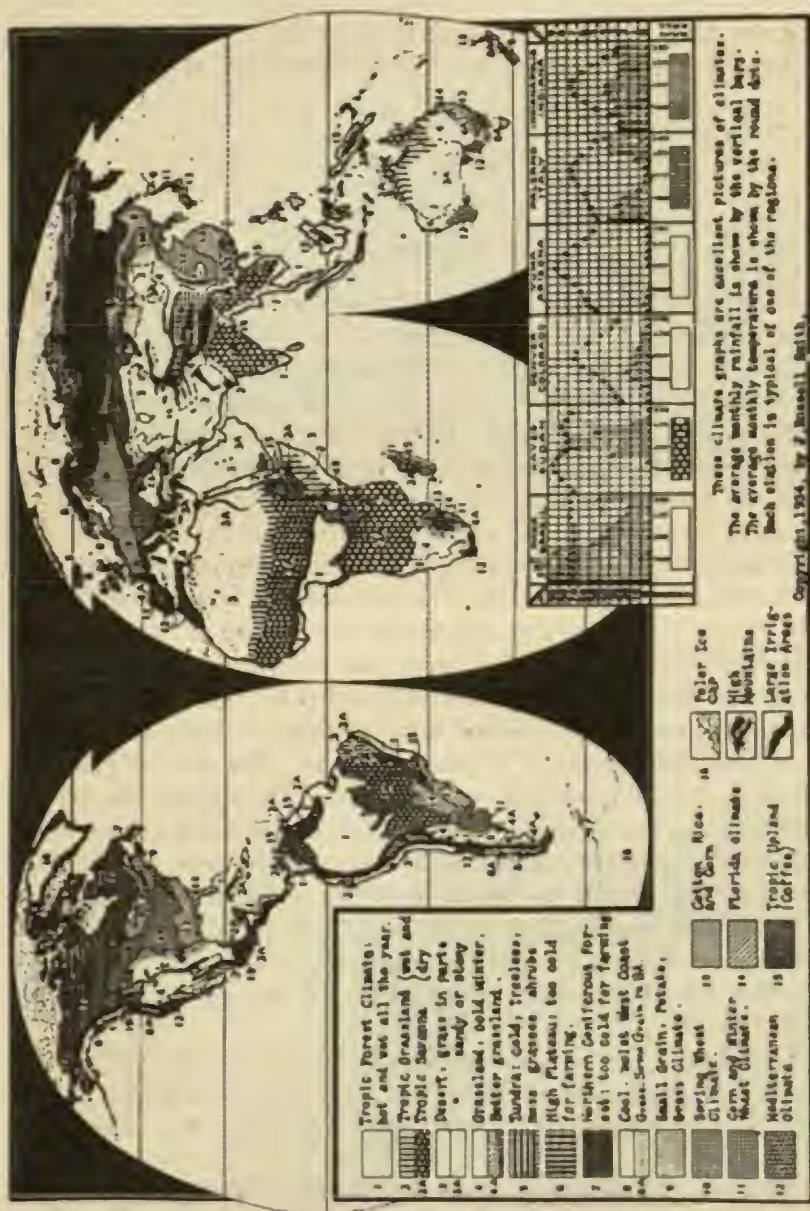


FIGURE 1.—Climatic regions. This map of climatic regions is probably the greatest of all maps in enabling us to understand the world in which we live. One can say nothing about North America or the United States or California as a whole; but Mediterranean climate (No. 12) is essentially the same in seven areas in six continents. Types 3, 4, and 4A are of especial interest to readers of this paper.

Not only did Stone Age man make a living, such as it was, in every type of environment—he and the women supported their offspring, maintained the race, formed communities, developed rules of conduct

(laws if you like), and created a literature in the form of folklore. They struggled with external nature, and, like the rest of mankind, with human nature.

These men and women in the smoky cave, the pit house, the skin tent, or merely sleeping in the open by fire or without it, were vexed by two problems that vex us today—the struggle for possessions and the lust for position, preferment, power.

Howard H. Brinton, a living Quaker writer of distinction, says: "Every one has within himself, a potential Hitler as well as a potential St. Francis."

With these two types in mind we should note that man's progress depends upon two things—first, keeping down his own potential Hitler, with the aid of education, morality, and religion; and second, fighting down his neighbor's Hitler. Controlling one's neighbor's Hitler presented a social problem, and for this man probably was forced to invent government.

In the Stone Age, as now, the external Hitler tendency, the bully, had to be kept in check. Control doubtless began as family fights and grew into clan, tribe, and other forms of group control. Even in prehistoric times, government, formal or informal, developed in all climes, in all societies, and in well-nigh myriad forms.

When man lived by collecting, only a few people could live together in any one place. Population per square mile was limited by the amount of available food. One group could force another group out of hunting grounds, but one group had difficulty in governing other groups. The political group, if one may use the word, was small. Although government may have been invested only in family, clan, or tribe, or in a village group, primitive government usually was inclusive in the scope of its control over individual freedom. Have not the elders of all generations said, "We do it this way"? Anthropologists are emphatic concerning the conservatism of primitive man. That is certainly one reason why the Stone Age lasted so long—long enough to achieve its amazing uniformity of tools and economy and its world-wide distribution, despite difficulties of travel.

Many anthropologists believe that this almost static period of human history may have existed for 500,000 years since our ancestors first began to use tools, and year by year the anthropologists are lengthening this period.

A new era began with the use of domesticated plants and domesticated animals. When some 97 or 98 percent of the half million years of human history had passed, perhaps 10,000 or 15,000 years ago, changes began to happen. Men and women, or perhaps we should say women and men, began to plant seed and to grow and cultivate crops. It is possible that the period of primitive crop growing is much older

than that. It was common in five continents. With a more stable and dependable food supply, human beings could settle down in a village for most of the year, or even, in rare instances, for a period of years. Soil exhaustion usually brought declining yields and a new patch was brought under cultivation. This process was repeated until finally the entire village had to move to fresh land.

Patch farming was a great improvement over the collecting economy. It permitted a larger village group and lessened the need to move from place to place. Patch farming gave new leisure, more time for mind



FIGURE 2.—This map makes it easier to consider the three valley cultures as one civilization. Why not call it the Irrigated Valley Civilization? Arrows show the trails of culture elements to China, Greece, and the land of the Hittites. (Base map copyright by Rand McNally & Company, Chicago.)

to play upon mind. Nevertheless, the problem of soil fertility usually kept the settlement from becoming a large one. It also prevented the group from remaining at the same place for any great length of time. These conditions existed on most of the soil areas of the world.

Patch farming was followed by the domestication of animals, especially in Egypt, the Near East, and Central Eurasia. The tough shoulders of the ox and donkey began to drag man's burdens for him some 6,000 years ago in Mesopotamia. The sheep and goat gave skin and flesh by herding instead of hunting. These animals also gave milk, as did the cow. The tamed offspring of the wild boar gave roast pork,

and the hen gave eggs without man having to seek the nests of wild birds in the forest. The new environment produced by the stimulus of crops, domestic animals, and larger residence groups seems to have produced a mental emancipation that gave new freedom to the inventive type of mind.

A NEW ERA, BASED ON LARGER HUMAN GROUPS, HAD ITS ORIGIN IN THE PERMANENT FERTILITY OF THE IRRIGATED VALLEYS OF EGYPT, MESOPOTAMIA, AND THE INDUS

In Egypt, Stone Age man found that the recurring floods fertilized his land each year with a thin but rich crust of mud. As a result he could stay in the same place generation after generation. Large settlements soon developed.

This was something new in the world. Revolutions emerged from it. Gradually many little governments came under one ruler, the governmental unit grew until finally the prowess of one ruler brought all Egypt, with its millions of people, under one government. For 6,000 years the Nile Valley has continuously supported its heavy population by benefit of the annual automatic deposit of mud. The Nile is the most regular, most orderly, most easily usable large river in the world. It has well earned the affectionate name of "Father Nile." Large areas of swamp along its upper reaches become automatic reservoirs that tame the sudden floods that trouble the lower valleys of most rivers.

The fertility of the irrigated lands along the Tigris and Euphrates was replenished in somewhat the same way. But, as compared with the Nile, the Tigris and Euphrates are wild and disorderly rivers. They have no controlling reservoirs. The maintenance of irrigation in Mesopotamia required more labor than in Egypt, and a continuously effective social organization was necessary. Like Egypt, Mesopotamia supported heavy populations, towns, cities, kingdoms more than 5,000 years ago.

The recent excavations of Mohenjo-daro and neighboring cities on the lower Indus show somewhat similar developments about the same time. These three populous valleys supported themselves by irrigation on wide-spreading alluvial lands with a dry, warm climate. Man has not yet imagined better conditions for agricultural production.

In these hot, dry valleys men lived under the compulsion of the need to work their crops in a season of flowing water, and under the near-compulsion of leisure in the season of drought. There was also the further compulsion of governments. These factors of surplus food, leisure time, large business enterprises, the desire for self-expression, and the compulsion of strong government produced writing, libraries, codes of laws, pyramids, and temples—cultures that were in many

respects much like our own. Among factors of production, we should not minimize strong government—witness the pyramids, a burst of energy covering only 150 years out of 5,000.

It is now generally agreed that the wheel and axle, the cart and the beast-drawn plow were first used somewhere between the Persian Gulf and the Syrian shore at or about 4000 B. C.—perhaps earlier. It is further agreed that this important invention was made only once in human history. The spread of the wheel and axle to all continents has been definitely traced from this one source.

Archeologists are continually finding proof that commerce existed at this early time between Egypt, Mesopotamia, and the Indus Valley.

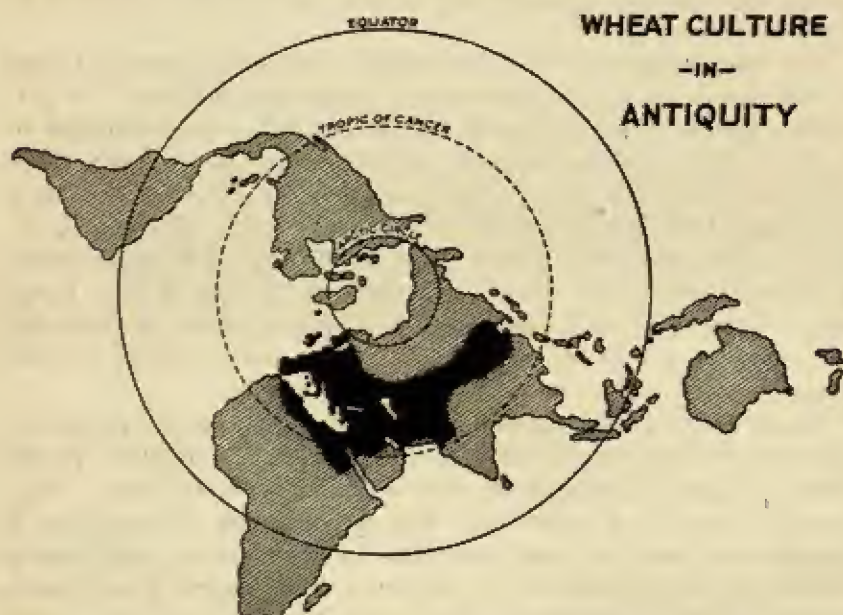


FIGURE 3.—Wheat culture in antiquity. (After Carl Bishop.) Wheat had climatic limitations to its spread. It does not thrive in the wet Tropics.

Because of these exchanges these earliest centers of heavy population, cities and city culture may legitimately be considered one civilization in a sense similar to our use of the term Western Civilization.

This new culture of the three valleys with its stupendous advance over previous cultures was, at base, a result of the enduring soil fertility. For the first time in human history large sedentary populations could depend upon the permanence of their food supply. Generation after generation men could live in the same place. They could accumulate things. They had leisure. When they learned to write, they soon recorded knowledge and built libraries in which to store it. Thus three dry valleys became the cradles of civilization

and finally the teachers of the human race. From this base many culture elements have spread to all parts of the world. It is fortunate for those of this generation that the Mesopotamians wrote on enduring tablets of clay.

Then, as now, men who traveled carried with them ideas, techniques, and various culture elements. A trail of fragments of painted pottery leads from Shushan, near the eastern edge of Mesopotamia, and marks the road by which culture elements went from Mesopotamia to China. Through this dry land a natural road proceeds from oasis to oasis. Where mountain streams reach the plains at the foot of the mountains



FIGURE 4.—Distribution of the traction plow before the age of discovery. (After Carl Bishop.) The plow had wider spread than wheat. It was drawn by ox, buffalo, and donkey, and occasionally by the elephant.

natural refreshment stations exist. No one knows how long these little Niles have been feeding humanity. These fertile spots encourage travel across Iran, western Turkestan, and eastern Turkestan. Thence the trail continues eastward across Mongolia and down the Wei River valley, past the present city of Sian and on to the great bend of the Hwangho at the southwest corner of the province of Shansi.

No one knows when culture elements first began to pass northeastward from Mesopotamia over these stepping stones of fertility. This seems to make logical the Chinese claim that Chinese civilization had its origin in the Sian Valley near the great bend of the Hwangho.

This Sian Valley was the first place at which this route across mountain and desert delivered culture elements from the west to men living in good farmland.

This first center of the present Chinese culture had a rare combination of qualities. There was enough rain to support agriculture, and there was loess soil. This wind-blown gift of deserts that lay to the west is the closest approach on earth to the perennial fertility of the annually flooding river valley. Let a farmer plow the top foot of loess and let the soil wash away or blow away, it matters not—the second foot is as good as the first; the twentieth foot is as good as



FIGURE 5.—Known distribution of the war chariot in antiquity. (After Carl Bishop.) The war chariot came later than the plow. It depended upon the horse. The open grassland of central Eurasia and the Zungarian Gate (see figs. 6 and 18), an opening in the mountains west of China, furnish an easy passageway for men and ideas.

the second. Here then was another basis for an agriculture that could endure for centuries.

Generation after generation of men in the Wei Valley loess had the advantages of permanent fertility of the soil. Meanwhile the mind of man was fertilized by the arrival of cultural elements from Mesopotamia and the steppes. Still another stream of culture elements came to the Sian Valley from India, by way of the Burma Road. Sinologists say that fowls and rice were early arrivals over this route.

Besides the fertility base of loess vouchsafed by nature, the farmer adopted two fertility measures whose effectiveness is unrivaled by

anything outside the three great valleys. The Chinese method of cultivating rice in the paddy fields conserves soil perfectly and adds a touch of fertilizing mud. The other fertility device is that of collecting human excrement and returning it to the land. The Chinese have systematically applied this device for many centuries. It is well-nigh impossible to overestimate its importance as a means of support to Chinese civilization. Thus, fertility, enduring or preserved, stands out as the basis for the development and endurance of the Chinese civilization. These factors gave to these people the combination of time and continuity similar to that which accompanied the rise of cultures in Egypt and Mesopotamia.

The Chinese received many culture aids from the outside, but they devised their own system of writing and made many important inventions on the basis of their own native wit and the stimuli from the



FIGURE 6.—The Eurasian grassland, as shown by Mackinder in "Democratic Ideals and Reality," Henry Holt & Company. Note the scale of miles.

Near East and India. China may be regarded as one of three subsequent cultures that leaned heavily in their beginnings on culture elements from the three great irrigated valleys.

Culture elements traveled northwestward as well as northeastward from the centers of its beginning. Between 2000 B. C. and 1400 B. C. the Island of Crete was one of the most highly civilized places in the world. There is evidence that the people of Crete learned from the people of Mesopotamia by way of Anatolia and the stepping stones furnished by the Aegean Islands. Knowledge also must have traveled by direct voyages to Egypt, only 340 miles distant, there is so much evidence of interchange between the isle and the Nile.

The Aegean culture was spreading from island to island, and had produced the famous cities, Tiryns and Mitylene, on the mainland of Greece, whose cultural remains, so unlike those of the Classic Greeks,

were long a puzzle to archeologists. Knossus, the ornate and learned capital of Crete, was destroyed about 1400 B. C., nearly 3,400 years ago, but that date was more than 2,000 years after the Sumerians had developed a complicated civilization and were filing away its amazing records on their durable tablets of clay.

While culture was spreading outward from its places of origin something was brewing in the grasslands of central Eurasia—that vast unbroken plain that stretches from the Carpathians to the Altai and



FIGURE 7.—The question marks suggest the area, limits unknown, from which the grassland poured out its surplus sons upon their migrations, so destructive to the advanced cultures of the three valleys. (Base map copyright by Rand McNally & Company, Chicago.)

Tian Shan, and from the Caucasus and the mountain rim of Iran to the Great Northern Forest.

This vast grassland was an inhospitable area for the Stone Age man before he had domestic animals. There was grass, of course, on most of its extent, and fleet-footed game. But wood and natural shelter were scarce except along the mountain and northern forest borders and along the banks of the few streams that crossed the plain. The patch farming of Stone Age man was largely limited to these spots

in the vast plain, such as the banks of the Oxus, Syr Darya, Don, Volga, and other rivers that were favored with wood, water, and possible garden patches.

A new and very different era began when the man of the plains got sheep, goats, cattle, and, lastly, the horse. The steppe people domesticated the horse (E. A. Speiser, of the University of Pennsylvania, concurs), and it became thoroughly integrated into every feature of the life of the people of the steppes. A new force, a new dynamic had appeared upon the Eurasian scene—the man on horseback. Here was revolution. It upset the affairs of man and was far reaching in its effects. Indeed, the man on horseback has had but two analogs in human affairs—steam transport and the airplane.

Carl Bishop, of the Freer Gallery of Art in Washington, says that the Indo-European languages were developed by these horse-using people on the steppes somewhere in southeastern Europe or southwestern Asia. He further states that these people whom we call Indo-Europeans had the word for wheeled vehicle before they separated into eastern and western groups. Louis H. Gray concurs.

These Indo-Europeans of the steppes and the horse-using Turanians who appeared later in the same area, have profoundly influenced the history of Europe and Asia, both as spreaders of culture and as destroyers of states and civilizations. It is as destroyers that they made their conspicuous contribution.

The grassland nomad lives by flocks, the flocks live by grass. Animals must move to obtain grass, and man must move with the animals. The nomad has mobility—here today, gone tomorrow—and mobility is a very important factor in warfare. It is also a sad fact that the grassland can produce more men than it can feed. Thus there exists the expulsive force of hunger. These factors make migration so easy as to be almost a part of the social organization. Many will be familiar with Ellsworth Huntington's thesis to the effect that periods of drought and scanty grass made an expulsive force that sent Central Asian nomads to overrun surrounding lands. Farmer peoples living east, west, and south of the Eurasian plains had abundant and oft-repeated cause to mourn the fact that such a region as the Eurasian grassland existed.

About 2000 B. C. bands of nomads from the steppes began working their way around the western end of the Black Sea and southward through Thrace and into Greece. They were shepherds accompanied by their flocks and with rude carts loaded with household goods and drawn by oxen. These people later became the ancestors of the Classic Greeks. By 1400 B. C., or in about 600 years, these shepherd migrants had learned from the more cultured Aegeans to build ships. In their ships they sailed to Crete and conquered it. These barbarians burned

the palaces, libraries, and temples of Knossus. Those of the learned and cultured Cretans who could do so fled in ships to the still civilized shores of Asia Minor, Syria, and Egypt.

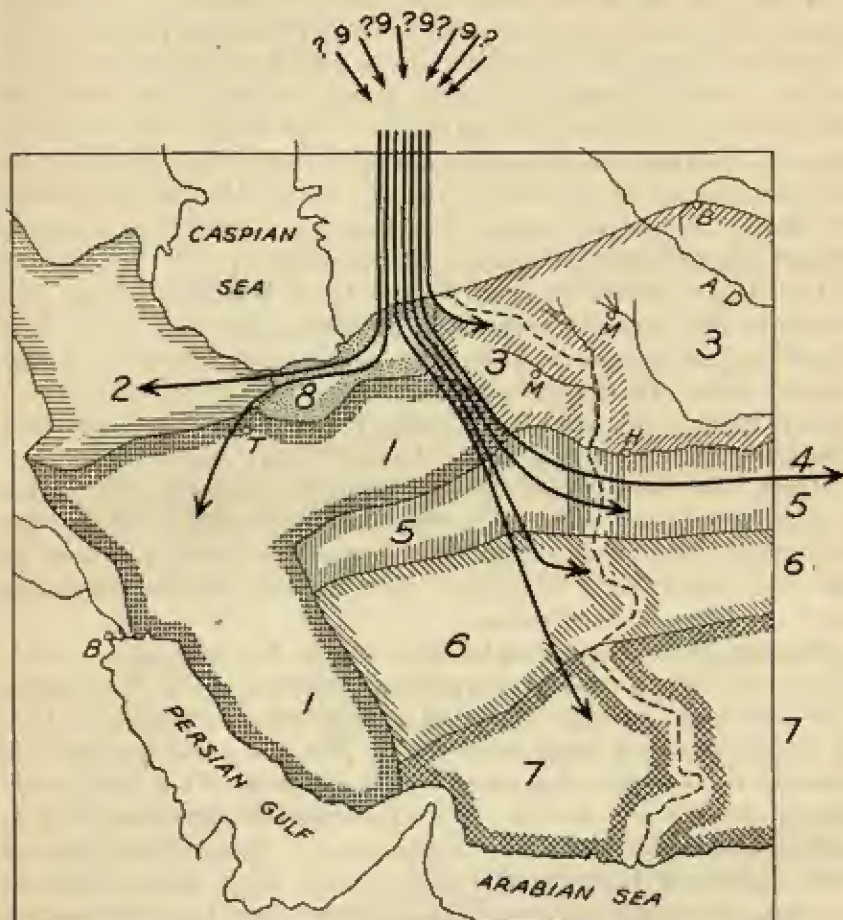


FIGURE 8.—Louis H. Gray, specialist in the origins of languages, presents this map to show the locations of various groups of Indo-Europeans after they had seized their lands in the plateau of Iran and Turkestan. 1, Persians; 2, Medes; 3, Margians and Bactrians; 4, the oft-traversed route to India; 5, Drangianians and Anachorianians; 6, Carmanians; 7, Gedrosians; 8, Hyrcanians; 9?, Indo-European homeland before dispersal. Note the present boundary of Iran (Persia).

T, Tehran; *H*, Herat; *M* (west), Meshed; *M* (east), Merv; *B*, Bukhara; *A. D.*, Amu Darya.

While the Greeks in the second half of the first millennium B. C. were driving civilization back toward its center, others of the Indo-Europeans of the steppes had passed north of the Caspian Sea and entered the plateau of Iran. They lingered there for generations—

long enough, according to Prof. Louis Gray of Columbia University, to produce the literature known as Vedas. They then divided, one group went southwestward into Mesopotamia and the other southeastward into India. This common origin in the steppes explains the remarkable similarity of the Greek and Sanskrit languages.

Beginning about 1200 B. C. many waves of these Aryans went into India. They overwhelmed the Indus Valley cultures. Prof. Walter Von Brunn, of the University of Leipzig (*Science News Letter*, Feb. 19, 1938), pointed out in 1938 that the remains of Mohenjo-daro, Chanhu-daro, and other Indus Valley cities of 3500 B. C. had no signs of having had walls or other fortifications. From this fact he inferred that continuous peace prevailed in the era before the eruption of the horsemen from the steppes. Perhaps this was the Golden Age.

These cities on the Indus plain had houses of well-burned brick. The present inhabitants of this area live in mud villages. Fifty-five hundred years ago Mohenjo-daro, built of brick, had a sewer system equal to that of Pompeii and other Roman cities that were built more than 3,000 years later.

All this the northern invaders destroyed—destroyed it so completely that we only learned of its existence by accidental discoveries in the twentieth century. Imagine if you can the thoughts and feelings of the cultured people of Mohenjo-daro as these early Nazis destroyed a city that had stood for centuries in peaceful prosperity.

India received many waves of these new raw men from the steppes. As a result Indo-European languages prevail today over large areas in northwestern India. The other results of these migrations can be observed today by anyone who passes northwest from southern India to the Khyber Pass and observes the gradual change in the color of the skin of the inhabitants. The color of native skin is black in southern India, white in the Khyber Pass, with various shades between.

The culture that originated in the warm and fertile valleys spread eastward to China, westward to the Aegean, and also, at an early date it spread northward to the highlands of Iran and Armenia where, as in China and in Crete, a civilization arose in part on borrowed culture elements.

In the third millennium B. C. non-Indo-European peoples in what we now call Armenia had a considerable culture, with cities and written language. Babylonian colonists settled among them, and the Mesopotamian cuneiform characters were added to their writing.

Early in the third millennium there came among them a migration from the steppes, "an Indo-European conquering people called by us 'Hittites.'" The invaders stayed, learned, increased, and made an empire. Recent excavations show that Hittite scholars mastered

six languages and were in "no way inferior to the Babylonians and Egyptians" (*Encyclopaedia Britannica*). Hittite armies conquered Babylon.

In 1685 B. C. a band of people called Hyksos, whose leaders are said by Speiser to have come from Turkestan, organized an army in the Hittite area and proceeded to conquer Egypt. This expedition took the horse to Egypt for the first time. The horse-drawn chariot of the Hittites was an early kind of "blitz" warfare. It overwhelmed the Egyptians, perhaps with the aid of better bronze for the cleaving of skulls.

At this point in our narrative the record stands as follows: four civilizations—Crete, Indus, Mesopotamia, Egypt—overrun by the horse-using Indo-European barbarians from the steppes. It was indeed fortunate that the seed of civilization was not destroyed by these conquests.

The Hittite empire fell before the next wave of Indo-Europeans, horsemen from the steppes. These were called Phrygians. These horsemen entered Asia Minor by way of the Hellespont. Like the Greeks at Knossus the Phrygians destroyed so well that it was only at a recent date that we knew much about them, and only in a very recent day that scholars deciphered the Hittite writings. Fortunately, these people wrote on bricks of clay, rather than the perishable and ephemeral rubbish on which we write so voluminously.

This episode of the Hittites can almost be considered the West Asian history cycle type, a type that is repeated through several millennia. Witness its operation in another group—the Scythians.

Herodotus described the Scythians (sometimes called a tribe of Cimmerians) as being nomads of the steppes north of the Black Sea. The Scythians followed their flocks on the open steppes in the summer, back to the shelter of the wooded stream banks in winter. The men rode horseback with their trousers—a steppe invention—tucked into their boots—another steppe invention. The women rode in wagons. The details of their life sound strangely like those of the present-day Kirghiz of Central Asia. Horse flesh and mare's milk were standard articles of diet. The abode was a tent of felt.

In the seventh century B. C. there was much movement of peoples on the steppes. "The Scythians overran and frightfully ravaged wide areas of Central Asia and Eastern Europe" (Bishop). Some crossed the Hellespont into Asia Minor, which they ravaged, and where they stayed for a century. Some went somewhat farther east and developed a kingdom in Ecbatana, within the present kingdom of Iran. Thus strengthened, refreshed, and multiplied, but still full of the barbarism of the plains, the Scythians harried the Assyrian kingdom, destroyed Ninevah and other cities, and advanced to the gates



FIGURE 9.—Areas of language groups. (After Louis H. Gray.) They mark the extent of heavy migrations.

The Indo-Europeans dominated northern India and even Burma so thoroughly as to leave their language. The original Dravidian speech holds the south of India and an island of Munda-Mond-Khmer (Indo-Chinese) holds out in the Ganges Valley. The Sino-Tibetan has pushed down and crowded Munda-Mond-Khmer into a corner.

The Turco-Mongol-Tungus group has pushed the Japanese group into corners on the east and cut the Indo-European areas in two on the west. The Hamite-Semitic has a crowded Indo-European in the Mesopotamian area. The Arabs left Islam in Iran but not their language.

The Indo-European block holds nearly all Europe except the Finnish area, the Hungarian remnant, and the Basque and Caucasus areas. The Caucasus Mountain area seems to have been an island of human refuge in the sea of migrations. It contains much linguistic and human flotsam and jetsam. It is said that 72 languages are spoken in Tiflis.



FIGURE 10.



FIGURE 11.

FIGURES 10 AND 11.—This record from an old Chinese tile tells us why the Chinese built the Great Wall. A new blitz had come from the grassland. The horseman with the two-piece bow seems to have been well nigh irresistible on open land, hence the wall. (After Carl Bishop.)

of Egypt. The Scythians then disappeared from history—probably absorbed. But note the evolutionary steps. A horde of nomads had left the steppes, harried the plateau. They tarried for a few generations. Almost surely their numbers increased, and they mustered strength in that land of better pastures and scattered oases. They then moved on to a career of conquest and rapine in the fat lands and rich cities of the plain. Then the melting pot absorbed them. That is the cycle. It occurs and recurs through nearly 3,000 years B. C. and plenty of times later.

The exploits of the Medes and Persians and of the Macedonians, conquerors all of Babylonia, fit closely into this pattern. The horse, the most spectacular contribution of the steppes, has played a curious and striking part in man's affairs in Eurasia. Bishop thinks that the Scythians may have been the first effective cavalymen. Armed with a compound bow, which seems to have been an invention of the north, a cavalryman could ride circles around a charioteer. Hence, the use of chariots in war declined in the Near East after the Assyrians, in the ninth century B. C., adopted cavalry from their enemies, the Scythians.

Man's experience in learning to use the horse serves to illustrate the stupidity of man rather than his cleverness. Perhaps most persons have thought of the horse in ancient history as a beast of burden, drawing the plow, the cart and the wagon with supplies for home or the army, with gentlemen and generals riding on comfortable saddles. Not so. It is now known that the first important use of horse in harness in the Near East was a thousand years at the war chariot. For this service it was speed that counted, not ability to draw heavy loads.

The chariot was distributed to Ireland and Korea between 2500 and 1000 B. C. After centuries of using the chariot as an instrument of warfare men began to fight from the back of the horse. But it was more centuries before the stirrup was invented. Moreover, man used the horse in harness for more than 3,000 years before a method was devised whereby a horse was fastened to a wagon by means of traces. Only then could a horse pull with more than a small fraction of its strength.

The shoulders of the ox and donkey are higher than are the necks. These beasts with yokes upon their shoulders or upon the head of the ox, pulled the plows and wagons of antiquity. The anatomy of the horse does not encourage yoking. Nevertheless the ancients fastened the yoke to a band around the neck of the horse. If the horse pulled with a considerable fraction of his strength the band pressed upon the windpipe and jugular vein and choked him down. This harness also held his head high, but when a horse pulls a load he puts his

head down. Pictures of war chariots show they did not carry much load, and Roman records verify.

Early uses of the horse sift down to this—meat supply, milk animals, assistant to the herdsman, the pet of princes, for pageantry, religious ceremonies, and war—especially war.

The horseman with a two-piece bow was the greatest "blitz" before gunpowder. This bow seems to have brought cavalry to the fore. The horseman with a lance was not so potent. This bow brought the horse to his Golden Age, to his zenith as an influence in the affairs



FIGURE 12.—The lightly shaded area shows the bounds of the empire of Attila, the Hun, about A. D. 450. The heavily shaded area shows present area of Hungarian language. (Base map copyright by Rand McNally & Company, Chicago.)

of man. From the beginnings of cavalry with the Scythians, about the ninth century B. C., to the date of the effective use of gunpowder, more than 2,000 years later, the cavalryman of the Eurasian grasslands almost continuously harassed the settled cultures upon the grassland rim and often smashed them at will. Thus the horse, the great contribution of the Eurasian grasslands to history, had several millennia during which his relation to sedentary societies was not primarily in the field of economics, but in the field of war; not primarily at defense, but rather the war of offense. The horse was an instrument of conquest and destruction of peoples, cities, governments, and social organizations.

In the Chou kingdom in China, 1000 B. C., the minister of war was known as "The Master of the Horses." The Chous had no currency. Taxes were collected in kind, and the chief tax gatherers were known as "bullock drivers." For many centuries over wide areas in three continents kingdoms were measured by the number of chariots they could put in the field. (See King Solomon.)

A recent writer, Bates, emphasizes the acute shortage of power among the Romans on both sea and land. This power shortage led to the use of the galley slave at sea and of slaves to turn the mill and



FIGURE 13.—The extent, A. D. 750, of the caliphate, the Arab Mohammedan empire founded by Mohammed. (Base map copyright by Rand McNally & Company, Chicago.)

to do other drudgery on land. Bates alleges that Roman wars were often little more than slave-gathering expeditions.

In the ninth century A. D., someone, apparently in France, invented the horse collar and traces. A horse could then pull a load. Then, as Mr. Bates tells us, horses could really work and enter the economic realm. Horsepower became cheaper than slavepower, and slavery gave way to serfdom. As mechanism improved, serfs became freemen. Inventions gave man equipment that permitted him to emerge from the slave age. At a much earlier time inventions had ushered in the Stone Age. Most important inventions change man's relation to some part of the earth.

The horse, especially the horse bearing grassland man upon its back, seems to have carried destruction to ancient societies in a way that suggests a strong resemblance to the work of the airplane today.

CHINA AND ITS RELATION TO THE GRASSLAND

The relations of China with the grasslands of Central Asia fall into two epochs. In the first epoch China received culture elements. In the second epoch China received conquerors and destroyers.

Considerably before 3000 B. C. Babylonia had a well-developed culture which included writing and a complete mastery of work in bronze. Babylonia also had wheeled vehicles, ox-drawn plows, wheat, many other crop plants, and all the common domestic animals except the horse (Bishop).

There is no evidence that China had knowledge of metals before 2000 B. C., but 500 years later peoples ruled by the Shang Dynasty in the central and lower Yellow River basin had a mature and developed system of writing, evidently homegrown. These peoples also had a skilled technique for working in bronze. Bishop says, "Bronze working was carried to a pitch of technical and esthetic excellence hardly if ever equalled in later times in any land." Much of this craftsmanship was undoubtedly borrowed, together with many plants and animals, from the Near East. It had taken the Mesopotamians several thousand years to develop these things.

Before Chinese contact with the Near East, the Stone Age man of the loessial area on which Chinese culture is believed to have developed, was a sedentary agriculturist. He lived, at least for the colder part of the year, in a pit house which gave unusual opportunity for the preservation of archeological records. These pit dwellers had dogs and many domesticated pigs. As early as the fifth millennium B. C. they cultivated millet and some leafy plants (Goodrich).

There is no sign of fortification about their villages until culture elements from the Near East appear—sheep, and bronze or copper arrow tips. The need for defense had come. The villages of the pit dwellers now have earthen walls. These tillers of the loessial lands are learning unpleasant things from the west whence they had derived so many useful things.

About 1050 B. C. (according to Bishop), the Shangs were conquered by the Chous, assisted by rebellious Shang subjects. The Chous came in from inner Asia—conquerors from the grasslands.

Ellsworth Huntington will smile with satisfaction at the mention of the Chinese tradition to the effect that the Shang Dynasty came to its end during a period of protracted drought for which the king was held responsible because he neglected to observe the proper rites.

Bishop states that the conquering Chous had a culture much like that of the Aryans who invaded India about 1200 B. C. About this time, also, other outsurges of steppe peoples went into Europe, southwest Asia, and Egypt:

Shang refugees fleeing before men from the grassland carried their culture eastward and southward to outlying regions hitherto barbarous. This oft-repeated process of culture spreading is now being again repeated as the educated Chinese from the westernized east coast of China move their colleges and industries to the conservative western uplands to escape the Japanese destroyer.

In the first millennium B. C. this process of grassland invasion and eastern culture dispersal was repeated several times. The unification of many kingdoms into one Chinese empire is commonly attributed to the fact that about 300 B. C. one of the western kings adopted a new technique of warfare from the barbarian enemies of the steppes. This was the mounted bowman with the two-piece bow (fig. 11)—an irresistible blitzkrieg much superior to the lumbering chariot, the preceding blitz.

The Great Wall of China rose as a tribute to the marauding horsemen of the steppes. One might almost say it is a monument to the horse. This, the greatest structure in volume reared by man, was built steadily during the seventh, sixth, fifth, fourth, and third centuries B. C. and often thereafter even as late as the middle of the eighteenth century A. D. Although the wall was designed to keep the nomad of the steppes out of the farmlands, it was only a limited success as is shown by the conquests of China by Tatars, Mongols, and Manchus. These cavalymen from the steppes could conquer China. They spread terror and rapine and made periods of chaos. The conquerors established dynasties. The dynasties melted away. The Great Wall still remains, 1,400 miles of it, in varying degrees of decay or ruin. But the nomad conquerors that rode through the wall in shouting triumph have disappeared completely, having been absorbed by the great mass of the Chinese people. Meanwhile the Chinese peasant still keeps on with his not yet so greatly modified neolithic type of agriculture.

ROME AND THE NOMADS FROM THE EAST

The unfortunate experiences of the late Roman Empire with the seminomadic Germans and the Huns (Turanians, not Indo-Europeans) of Asia and Mongolia are a standard part of school history. Bands of marauding horsemen, recognizing no law but the power of conquest, came out of the land north of the Black Sea, crossed the Danube, harried without mercy the eastern empire and collected tribute from Byzantium itself. Eastern Goths, Western

Goths, Vandals, Huns, Alans, Bulgars in turn punished the provinces of Rome both east and west for having been prosperous enough to produce material worthy of pillage.

The Bulgars remain as a name—their language has been absorbed by that of the Slavs whom they conquered and ruled. The Alans melted away as did the Scythians in the fat lands of Mesopotamia a thousand years earlier, and as the Mongols did in China a thousand years later. Many of the Huns of Attila's empire merged with the conquered, but one group went back to the grasslands of south Russia. Some 400 years later they returned to the plain of Hungary, where today they are the only remaining citadel of their language.

THE ARABIAN GRASSLAND EXPLODES

The seventh and eighth centuries of the Christian era witnessed the entry of the Arabian grasslands into the history of Eurasia in a large way. It was not the first time that Arabia had played a part in the history of lands beyond its border. One of the first recorded conquerors of Mesopotamia was Sargon the Akkadian, 3800 B. C. Sargon was a Semite, presumably from Arabia. Arabia is regarded as the original Semite nest.

In Roman times succeeding generations of Arab horsemen harried the Roman Empire. As the seventh century A. D. opened, Arabia was a political chaos of independent oasis settlements and endlessly quarreling nomad tribes.

A genius appeared upon the scene in the person of Mohammed, who preached patriotism and religion. He used the sword to advance his precepts and when he died in A. D. 632 Arabia was united.

The followers of Mohammed started a career of wider conquest. The Arab horsemen and camelmen rode east, west, and north. In a few years they had conquered Mesopotamia, Persia, Syria, Palestine, and Egypt. In less than a century they had crossed the Ganges and the Pyrenees, conquering all the lands between. Their defeat at Tours in France in 732 by Charles Martel, who drove them back into Spain, is one of the very important turning points of history.

THE MONGOLS AND THE TATARS

The eruption of the Arabs from their grassland was unrelated to similar happenings in the greater grassland of the present Russian domain. The central grassland of Eurasia kept on producing horses and men and marauding. In the ninth century a Russian chronicler recorded one of their many pillaging raids. "Whence they came," he lamented, "God only knows, and whither they went, God only knows, but while they were here they were terrible."

Unfortunately, later generations of eastern and southeastern Europeans knew more than this about the Mongols and the Turks. These sons of the grassland came and remained to rule.

Genghis Kahn (Perfect Warrior), 1162-1227, son of a Mongol chieftain, was a supreme genius. He was probably the greatest cavalryman that ever lived. In 30 years Genghis the Cavalryman spread his empire eastward to the Yellow Sea and westward to the Adriatic and the Baltic. Medieval Europe salved its sore vanity by saying that Genghis overwhelmed by myriad numbers. Not so. He won by disci-



FIGURE 14.—The area with NE-SW. shading shows the Mongol empire, A. D. 1300, the largest block of land ever ruled by one organization. The area with NW-SE. shading is the area ruled by Tamerlane, boastful of his pyramid of 70,000 human skulls. (Base map copyright by Rand McNally & Company, Chicago.)

pline, strategy, and tactics. He was a master of speed. The armies he defeated were usually much larger than his own, but he had more men at the point of combat than had the enemy—"The mostest men there fustest" (Forrest, C. S. A.). In one forenoon Genghis left 70,000 Europeans dead on the plain of Hungary, and then "reduced three quarters of Hungary to ashes."

It is reported that the strategy and tactics of Genghis Kahn have been most carefully studied by Hitler and company in five different compendious reports. Equipment may change, but the effectiveness of strategy and surprise remains. Genghis seems to have been a true

Nazi. He softened up prospective victims by propaganda, got information by spies, and attacked because he thought he could win. Details of his equipment and effective methods stand in reference books for those who wish to read them.

These Mongols conquered cities but camped without, in tents, as nomad warriors should. As he walked through a gutted Russian city a Mongol warrior kicked a bag of gold coins out of the way, remarking as he walked on, "a heap of good it did him."

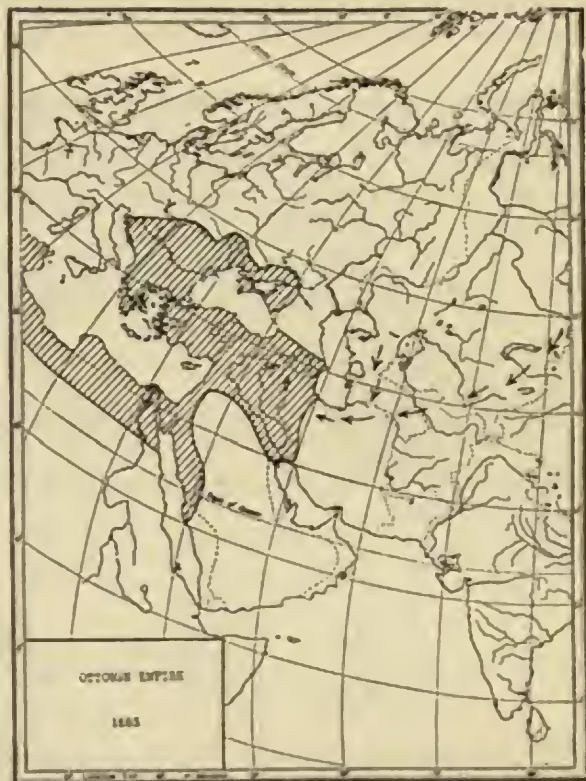


FIGURE 15.—Arrows show the trail of the Ottoman Turks out of Central Asia into Iran and Anatolia. Shaded area is Ottoman empire at its peak, 1683. V=Vienna. T=Tours, the highwater mark of Islam in western Europe, A. D. 732.

It is said that Genghis' generals urged him to cleanse North China by massacring the millions of agricultural human vermin who inhabited it. Genghis said "No," but his successor slaughtered the entire population of Baghdad, perhaps some 700,000 in number.

If Russia has been somewhat backward in comparison to some other European countries in recent generations, we should remember its complete submergence beneath the Mongol horde nearly a thousand years after the Roman Empire had its somewhat similar but less

thorough destruction at the hands of mobile horsemen from the steppes. Parts of European Russia are still inhabited by several groups of the descendants of these Mongoloid Asiatic invaders. Their numbers run into millions. We might call them, and the Hungarians and the Finns, Asia's return for the settlements of Indo-Europeans in southwestern Asia. The Turks continued this reciprocity with ferocity.

THE TURKS

The Hwang Valley seems to have been the center of peoples who are called Mongoloid. Central and north central Asia was the center



FIGURE 18.—Shaded area shows Russian conquests in Asia since 1580. Gunpowder and wheels quelled the horseman of the steppes.

for peoples called Turanian. The names Turki, Turcoman, or Turk have been variously applied to a dozen or more ethnic groups living west of the Great Wall and close kin to Mongol and Hun. The mobility of these horsemen of so-called Turkish stock was so great that in a short period they were to be found at Lake Baikal and also in Morocco, 7,000 miles distant. When the Russians took Merv less than 100 years ago, the Turcomans of the nearby steppes were known by their neighbors as "the man-stealing Turks."

The Turkish group that conquered Constantinople has repeated the southwest Asia historical cycle with variations. They came from

Turkestan, crossed a corner of Persia, and settled in Asia Minor. There they increased, organized, and crossed the Bosphorus. Passing the walls of Constantinople the invaders established themselves in southeastern Europe in the early 1300's. After generations of war they took Constantinople in 1453 and extended their empire into Hungary and south Russia. In 1683 the Turkish siege of Vienna was raised by John Sobieski, of Poland.

If you look at the map and locate Tours, the northernmost limit of the Arab invasion, and Vienna, the westernmost limit of the Turkish invasion, you will see that Christendom has been subjected to a men-



FIGURE 17.—Human overflow from northern and southern grasslands, as shown by Mackinder in the book "Democratic Ideals and Reality," Henry Holt & Company. Small wonder that Mesopotamia, once so fruitful, has lain almost idle and almost empty for centuries and centuries.

acing pincers movement. Fortunately, the different sides pinched in different centuries.

If anyone is inclined to criticize the Balkan peoples for some cultural, or especially political, shortcomings, let him remember that for 500 years (1326-1878) the Balkan peoples were subjected to the tyrannous misgovernment of the Turks, from which they but recently escaped.

During much of this long era of Turkish rule there was something like guerilla warfare here and there in the broken area we call the Balkans. In such a time men think of chieftains, leaders, not such abstractions as democracy. In 1943 and 1944 we heard much about Mihailovitch and Tito—two more chieftains.

At the close of World War I, Michael Pupin, a Serb, and distinguished physicist of Columbia University, was the head of many Serbian organizations in this country. When Woodrow Wilson, at Paris, was big in the European news, Pupin remarked one day, "I don't want a college professor, I want a *king* and a *hero*."

The Turk ruled a wide empire of many peoples, but was able to establish his language only in Anatolia.

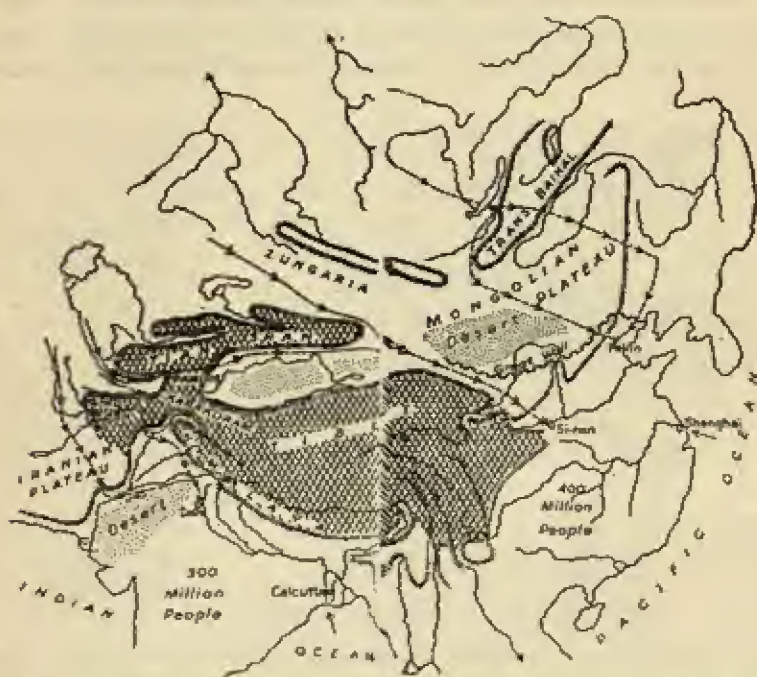


FIGURE 18.—Topography and routes of conquest and migration. Note the Zungarian Gate, opening a marauders' road from grassland toward farmlands. (From Mackinder, "Democratic Ideals and Reality," Henry Holt & Company.) The second route from the left is the Khyber Pass. No one knows the number of bands of migrants, marauders, or organized armies that have marched through that very favorable opening in the mountain wall. There were those of Alexander, Tamerlane, and George V. Today it has a strategic railway, and bristles with pillboxes perched high aloft on many commanding hills.

RUSSIA TAKES THE STEPPES

Gunpowder with muskets and cannon ended the career of the horsemen of the steppes after an undisturbed independence of unknown duration, and after about 4,000 years during which the horsemen overran almost at will their more civilized neighbors on the east, south, and west. In 1580 the Russians with muskets, cannon, and wagons crossed the Urals. In 300 years they subjugated the whole of central

Asia and all its horsemen right down to the mountain walls of Persia, Afghanistan, and the outer provinces of the old Chinese Empire.

The tables were turned. The mobile grassland horseman found himself dominated by a machine-using sedentary man from beyond the grassland border.

It is interesting to contemplate the almost unchanging continuity of two culture types: East of the Great Wall, in the good farmland of the Chinese plain, the man with the hoe, the mud village, the brick temple. This man was, and is, a peace-loving creature untempted by the lure of conquest, praying to be let alone in his garden. Instead he has been the victim of oft-repeated pillage.

West of the Great Wall the grassland man, riding a horse, living in a tent, menaced by perennial uncertainty of supplies of grass and water. His temptation to maraud was strong and oft-repeated. The mobile existence of the grassland man made it easy for him to raid and pillage. The grain bags of the man with the hoe offered an easy objective. Thus, for 4,000 years grassland culture changed but little and the raiding nomad never ceased his attacks. Almost any year cavalry could muster on the plains and in irresistible numbers appear unannounced in the farmland beyond the mountain. Thus civilization after civilization and empire after empire developed in the farmlands and fell before the man from the grassland.

Grassland society permitted and encouraged military power, often unlimited except by the whim and fancy of him who wielded it. Temptation to yield to the power lust was more frequent in the grasslands than in other environments. The power lust is unique among man's desires. The gratification of the desire for food, drink, sex, the pleasures of the chase, of workmanship, of the intellect, of creative art—the exercise of all these leads to satiety and sleep. But in terrible contrast, the lust for power grows by gratification. It runs away with the human spirit. At times it unbalances the mind. The Romans with the pitiful record of emperors before them had a word for it—"Imperial Madness."

History furnishes overabundant illustrations. To read "*Mein Kampf*" and contemplate the actions of the Nazis proves the present and continuing menace of unchecked power. The dangerous thing is that the power lust is born in all individuals. It is even shared by some of the quadrupeds.

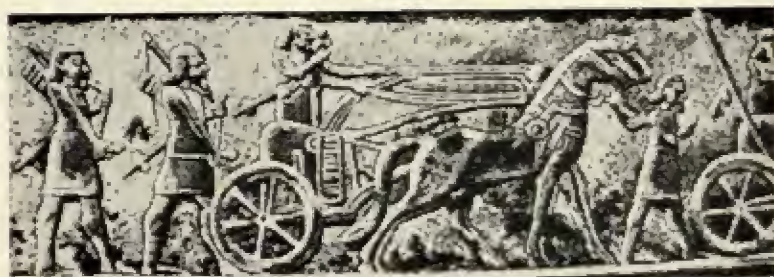
If the turbulent history of the Eurasian grassland has any message for this generation of men it is an imperative command to so organize our affairs that no race, nation, or group can get into a position of unlimited power over other large groups.

Gunpowder and the railway reduced grassland man to impotence. They made him the vassal of the man from outside whose machinery could outrun the horse and outshoot the horseman's bow or rifle.

But what about this Eurasian grassland as a stage and base of operations in the world of tooth and fang, but equipped also with plane and bomb?

Mackinder pointed out at the end of World War I that land-based air power would soon make the Mediterranean untenable to any kind of shipping. Here he showed himself a most true prophet. History has vindicated Mackinder. It has also vindicated Woodrow Wilson's dictum that if any people or nation is not safe, no nation is safe. Immensely strengthened is the argument for world organization to outlaw war. If our intelligence is any greater than that of the sheep or the cow we will strive for international organization that is equipped for:

1. The removal of international tensions before they make explosions.
2. The treatment of any war as we treat smallpox and rabies.



1. THUS DID SHALMANESAR, KING OF ASSYRIA (MESOPOTAMIA), CELEBRATE HIS VICTORIES, 840 B. C., IN "IMPERISHABLE" STONE.

(After des Noettes.)



2. TIGLATHPILESAR, 745-727 B. C., LEFT THIS MONUMENT TO HUMAN STUPIDITY.

Note the heavy tongue of the chariot higher than the horse's back and, far up the horse's neck, the choker to which the tongue is attached. (Compare fig. 1, above.) The Romans were not much better. Trajan, A. D. 70, celebrated his Dacian victories with a half mile or so of sculptures winding round and round his well-known column. There are horses there but no stirrup, no horse collar, no trace (attachment to horse's shoulder). Trajan's horses pulled less than those of Tiglathpilesar. Indeed they pulled not at all—according to sculpture. Men with dangling legs sat astride them.

(After des Noettes.)



SOUTHERN ARABIA, A PROBLEM FOR THE FUTURE¹

By CARLETON S. COON
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INTRODUCTION

The one corner of the Asiatic continent with which archeologists, ethnologists, and physical anthropologists have concerned themselves the least, for excellent reasons, is southern Arabia. This pardonable neglect stands in inverse ratio to the region's natural appeal and interest. The whole Arabian peninsula, from one standpoint, forms one of three vermiform appendices dangling from the main mass of Asia into the Indian Ocean. Arabia, southern India with Ceylon, and the Malay Peninsula, have all three served as culs-de-sac to old, discarded, and forgotten fragments of humanity, pressed out of circulation by the movements of more vigorous and more civilized groups to the north. The parallel between southern Arabia and the other two appendices is clear. The primitive Bedawin of the Hadhramaut, who form the substratum of that country's population, and the non-Arabic-speaking natives of Mahra and Dhofar, serve as the western counterparts of the Vedda, the Semang, and the Sakai.

But there is another facet to this comparison. Just as the brilliant Sinhalese civilization flourished in Ceylon, just as the Mon-Khmer civilization reached sculptural heights in the jungles of Cambodia and Siam, and Hindu culture was carried over into Sumatra and Java, so southern Arabia has at the same time played a second role, that of a hothouse of high oriental civilization in antiquity. Here flourished

¹ The purpose of the author in writing this paper is to summarize the existing information, available to him, concerning the prehistory, archeology, and ethnology of the portions of Arabia lying south of the twentieth parallel, especially the kingdom of Yemen and the regions of Hadhramaut and Dhofar, and the island of Socatra, and to interpret that data both historically and ethnologically. In so doing the author has drawn heavily on several sources: Maj. H. St. John Philby's articles in the *New York Times* of September 12 and 19, 1937; Dr. Cesare Ansaldi's book, "*Il Yemen*"; the sections written by Drs. Nielsen, Hommel, and Rhodokanakis in the "*Handbuch der altarabischen Altertumskunde*"; Van den Berg's "*Le Hadhramout et les Colonies Arabes dans l'Archipel Indien*"; "*Southern Arabia*," by Theodore and Mrs. Bent; and "*Arabia Felix*," by Bertram Thomas.

The bulk of the information comes from the aforementioned sources, most of the rest from the author's field notes. The interpretation, unless otherwise acknowledged in the text, is original.

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the famous kingdoms of the Sabaeans, Minaeans, Katabanians, and Hadhramautis, whose splendors were immortalized by the biblical account of Solomon and the Queen of Sheba. Under the encroaching sands of the Empty Quarter lie the feet of splendid temples and lofty skyscrapers, abandoned to the desert after the breaking of the Marib dam, and the shift of the frankincense trade from the overland route to the sea.

The peninsula of Arabia can hardly be called a unit. The Empty Quarter, probably the world's largest stretch of sheer and utter desert without oasis and without relief, acts as the center of a ring, about which are set the Arabian kingdoms, like jewels of different hue and luster. The Empty Quarter divides these kingdoms as no sea could, for one can sail across seas, and some, such as the Mediterranean, and the Indian Ocean, have acted in history as highroads rather than as barriers. There is no barrier so great as a complete desert. The Empty Quarter may be crossed by camels and has been so crossed over long periods of time; this has been proved by the personal experience and inquiries of Bertram Thomas. Such crossings, however, are extremely exceptional, and most of the inhabitants of Arabia today entertain only fabulous notions of the actual character of this extensive waste.

Although it would please exponents of pan-Arabian solidarity to think that all the Arabs in the whole peninsula and elsewhere form a racial and cultural unit, the truth is quite the opposite. Arabian unity north and west of the Empty Quarter may well extend into Syria, Iraq, and North Africa, but south of the great desert the vermiform appendix plays its retentive role. Here, small, ringlet-haired men, painted blue, swear mighty oaths over the tombs of Jnun, milk their cattle, sleep in caves, and initiate their sons in mass ceremonies of an Australoid character. These men are not Arabs in the modern, Islamic sense; they are the survivors of an earlier age.

Southern Arabia may be divided geographically into a number of discrete units. Most important politically, and in reference to population, is its westernmost segment, the divine kingdom of Yemen, where approximately 3 million farmers water their terraces and reap their barley under the spiritual sanction of their Imam. The Yemen consists geographically of two main parts, separated by a formidable barrier. The first part is the Tihama, a narrow coastal strip in which sand dunes alternate with fields of sorghum, and occupied by a mixed population of Negroid serfs from Africa and small elflike, brachycephalic men, whose racial origin is still a mystery. The barrier is a 10,000-foot escarpment, rising sheer from the coastal plain, crowned by a range of castellated peaks, and folded and eroded into countless valleys.

This escarpment has been almost completely terraced by man. On it grow crops of luscious fruits, various hard grains, and the entire supply of the world's finest grade of coffee. Beyond the escarpment stretches a vast upland plateau, sloping gently eastward and drained into the Wady Hadhramaut and the Indian Ocean. From the edge of the

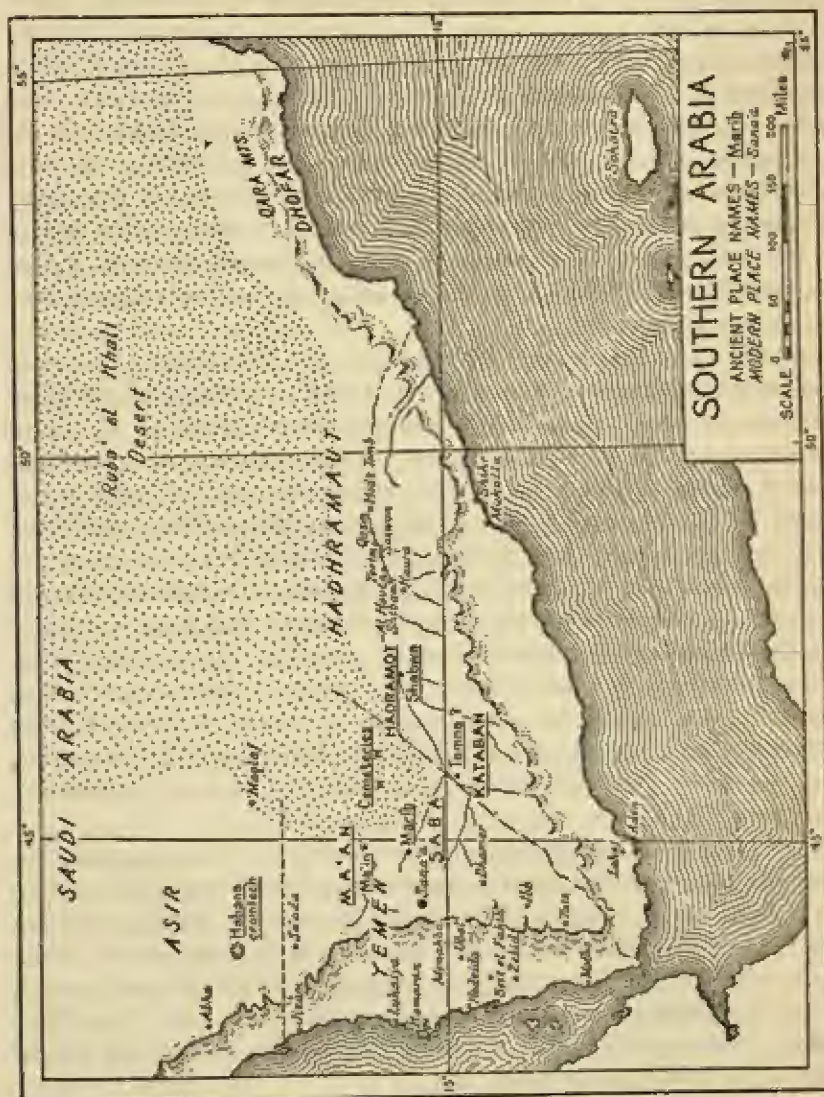


FIGURE 1.—Southern Arabia.

escarpment to the ill-defined border of the gradually encroaching Empty Quarter stretches a wide belt of terraced land on which great crops of grain are grown by the Imam's subjects. The desert borderland, itself once the seat of garden states watered by means of huge dams, is now occupied by a few scattered tribes of Bedawin, who make

their living by exploiting the natural salt deposits situated near the great city-sites.

To the east of the Yemen, and to the south of the westernmost extension of the Empty Quarter, lies the famous region called Hadhramaut, a country whose size diminishes as one approaches it. To the outsider, the Hadhramaut comprises most of Arabia east of Aden, west of Mahra, and south of the desert. To the Hadhramis themselves, it includes only the narrow valley which bears its name, and the string of towns built along it. The Hadhramaut, like the Yemen, is the seat of intense agricultural activity, but in a much more restricted sense, since only the river valley and the beds of its tributaries are actually productive, while the nearly denuded mountain region lying between the valley and the sea is used for camel pasture and the passage of caravans. The sea coast of the Hadhramaut is a negligible geographical expression, since the cliffs which hem in this valley to the south arise almost directly from the water.

East of the Hadhramaut lies what is, to most ethnologists, probably the most interesting section of southern Arabia. This is the half moon of Dhofar, a small coastal plain hemmed from behind by the Qara Mountains, against which the full force of the Indian monsoon unloads seasonal rain in abundance. Dhofar alone retains the damp tropical climate which, the geologists tell us, at one time characterized the whole southern strip of Arabia. In Dhofar survive mangrove swamps, miniature jungles of tropical palms, and on the slopes above the plain, an abundance of those small, fleshy bushes from which are bled the frankincense tears so greatly prized in the ancient world. In the highlands behind Dhofar survive pre-Arabic Semitic languages;² and a cattle culture comparable to that of the Toda of India on the one hand and of the East African Hamites and Bantu on the other, as well as certain customs and practices of a very primitive character.

When we leave Dhofar we enter the domain of Oman proper, but we are no longer in the strict sense concerned with southern Arabia. The bulk of Oman is situated in a latitude north of Mekka, and even with that of Medina. Except for the alleged Negrito strain in the population of Cape Musandam, its relationships are primarily with the valley of Mesopotamia and with the coast line of Iran. Southern Arabia, in the strict sense of the word, cannot be said to extend north of the twentieth parallel.

PREHISTORY

There can be little doubt that, during parts of the Pleistocene period, southern Arabia enjoyed a much more felicitous climate than it does at

² Thomas, 1937b.

present. The Empty Quarter, after all, is nothing but an eastward extension of the Sahara, a part of the general belt of arid uplands extending across vast expanses of Africa and Asia. Since the climatic history of the Sahara is now partly known, it is possible to reason by analogy with some hope of justification.

During the Pleistocene, a number of pluvial periods turned the Sahara, at alternate intervals, into a great plain of grass and parklands, drained by huge rivers which carved its deep wadies, now waterless and denuded, into sculptural masterpieces of erosion. In southern Arabia, the size and volume of the dry river courses bear evidence that the same process took place here as well, and that during these periods of abundant rainfall the Empty Quarter itself formed a grassy plain of lesser size, offering food and shelter to herds of ruminant mammals, and to man.

After the last pluvial maximum, Arabia, like the Sahara, began to dry out. The abandonment of Marib, the gradual disuse of the terraces along the Yemen escarpment, and the turning of the northern Arabs to pastoral nomadism with dependence on the camel, may all have been secondary manifestations of this increasing desiccation, and we have no evidence that the drying-out process has yet come to an end. Arabia today holds somewhat less than 6 million people. Five thousand years ago, when agriculture was already old but literate civilization new, Arabia might presumably have held twice that number. If we are to reconstruct the history of Arabia, however, we must turn back still farther, and postulate a time in which the whole southern border of the peninsula resembled the present Dhofar, and in which the Empty Quarter and the regions north of it were grassy plains.

At that time, it is possible that Arabia was a home of human beings of ancestral European type, and advanced beyond their fellows in the glacial north. It is too early, however, to present this hypothesis with conviction, for at present Paleolithic archeology in Arabia may be said hardly to have begun. In the Nejd, Doughty¹ found Paleolithic implements, in the form of hand axes; Henry Field,² in a motor trip across Transjordan and the desert border of Iraq, established the presence of Paleolithic industries from the Acheulean stage upward, while Philby,³ in his recent trip along the southern border of the Empty Quarter, has likewise discovered Paleolithic implements of nature as yet unstated.

Miss Caton-Thompson,⁴ however, has found paleoliths in situ in the Hadhramaut; these are of Levalloisian type, and poorly executed.

¹ Doughty, 1928.

² Field, 1934.

³ Philby, 1937.

⁴ Caton-Thompson and Gardner, 1939.

They seem to have been used over a long period of time. So far, none of the hand axes so typical of northern Arabia have been found south of the Ruba'el Khali, which was perhaps as much of a refuge area in Paleolithic as in historic times. In other words, the geographical forces which divide northern and southern Arabia into separate cultural entities today may also have operated as far back in human history as Pleistocene times.

Southern Arabia may also hold the answer to some of the problems concerned with the rise of the Neolithic economy in the Old World. The Yemen highlands and the corresponding highlands of Ethiopia seem to be old centers of terraced agriculture. In Ethiopia, a number of unique local species of cereals have been found. So far, the Yemen has escaped the attention of economic botanists, but this region may be of great interest in this connection. It is just possible that some aspects of the Neolithic economy may have developed in this area.

Megaliths, too, are present in southern Arabia. In his recent journey through Asir and the desert borderland of Yemen, Philby¹ noticed the presence of cromlechs similar to Stonehenge, made of double concentric circles of huge slabs of granite, with central corridors oriented to the east and west. He also found semicircular passageways, and vast fields of dolmenlike tombs both with and without corridors. Further study on the spot will be needed to determine both the age of these structures and their relationship, if any, with the megalithic complex in the Mediterranean and western Europe. At present, however, it would seem that they have a strong continuity, at least in an architectural sense, with the historic cultures of southern Arabia.

Aside from archeology, southern Arabia may contain the solution of an important question in the racial field: "What role did the southern coastal strip of the peninsula play in forming a connection between the frizzly-haired, deep-pigmented peoples of Africa and Oceania?" In Africa the general Negroid family is represented by true Negroes, Pygmies, and Bushmen. In southern Asia and Oceania, from India to Fiji, one finds various kinds of Negritos, all occupying marginal areas, as well as Melanesians and Tasmanians. There is probably some genetic continuity between the Negroids of these two major areas, and since the fringe of southern Arabia lies in between, some traces of whatever group served as link might possibly be expected to survive. Such a survival does actually occur.

The population of southern Arabia, aside from the Yemen, consists of two major elements—Mediterranean and Veddoid. In the Hadhramaut Valley, the agriculturists are predominantly Mediterranean; among the Bedawin, and among the wilder tribes of the Dhofar

¹ Philby, 1937.

region, the Veddoid element increases in importance. There is, however, a third element—frizzly-haired, short-statured, round-headed, which occurs among sporadic individuals, and which is presumably Negrito. Individuals possessing these traits are not to be confused with African Negro hybrids, who are well recognized and who are differentiated from the rest of the population in a social sense, nor with Somalis. The tribesmen of Cape Musandam, in Oman, are said to be predominantly Negrito.*

The tentative identification of a submerged Negrito strain in southern Arabia, which can be confirmed only by further work on the spot, leads one to suggest that the connecting link between the African and Oceanic Negroids may be Negrito—the only type which both have in common. It is very likely that the Negrito is an extremely ancient human type, as witnessed by its marginal position, and that it antedates in development both the African Negro and the Melanesian, which latter is probably a hybrid. Southern Arabia was presumably at one time merely a segment of the forested belt which the Negritos of the world occupied, and in it the Negrito factor may well antedate the Veddoid.

THE PRE-ISLAMIC KINGDOMS[†]

When we approach the problem of the literate city-states of pre-Islamic southern Arabia, we reach somewhat firmer, though still shaky, ground. We know that there were four kingdoms, from northwest to southeast: Ma'an, Saba, Kataban, and Hadhramaut. Their capitals were, in order, Ma'an, Marib, Tamna, and Shabwa. Of these four, Tamna has not even been located. Ma'an and Marib were visited by furtive epigraphers in disguise, in the 1880's, and then left unknown until 1935, when Hellfritz, under escort by the Imam's soldiers, was hurried through the latter. The same adventurer also passed through Shabwa equally rapidly. In 1936-37, Philby spent a total of 8 days at Shabwa and peered at Marib from a distant hill.

Under these circumstances, it is no wonder that our knowledge of these kingdoms is scanty. It is largely derived from Greek accounts, and from the translations of inscriptions—some copied in the cities themselves, others photographed and copied in the Imam's Museum at Sana'a, and still others brought out to the coast at Aden. Other objects in the Imam's Museum hastily examined by the author and by Dr. Schlobies, contribute further evidence. The Peabody Museum of Harvard University and the Semitic Museum of the same institution have small collections which await competent study.

* Wilson, 1928.

† The literary evidence upon which much of this section is based is drawn largely from Nielsen, et al., 1927.

Despite the paucity of information and the general lack of interest in this most important field, linking as it does the civilizations of two ancient worlds, the trade of the forger flourishes. The rare visitor to Sana'a is besieged by dealers in statuettes and inscribed stones, some blatantly poor and new, others clever and difficult to detect. Silver coins of the Sabaeans, however, are abundant, and a drug on the numismatic market.

What do these objects so far found tell us? Their surface message is clear. The kingdoms of southern Arabia, like that of the Nabataeans farther north, were in contact with the entire ancient world, from Rome to India and perhaps beyond. Objects of Roman, Greek, Egyptian, Mesopotamian, and Indian manufacture abound. Scarabs, amulets, bronze statues in the Roman manner, dragon-feet and grape-bunch ornamentation in the Syrian and Byzantine manner, and Grecian columns all witness the especial linkage of this region with the Mediterranean. The names of gods monotonously repeated, the abundance of seated votive idols and ex votos, from phalli to oxen, indicate a devotion to religion and a belief in divine cures. Animal figurines show humpless cattle of the long-horned variety, like those of Hottentot and Galla, dromedaries, horses, ibexes, and gazelles.

Bronze is the common metal, iron rare; gold and silver are not scarce. Microlithic flakes of ornamental greenish stone and of obsidian were apparently used as cutting tools and as arrowheads, along with metal. Palettes indicate the great use of mineral cosmetics, as in predynastic Egypt. Statuettes and bas-reliefs show the skirt or breechclout to be the common costume. The sculptural level in purely native art is not high enough to give us an accurate idea of the racial types present, except that the people were undoubtedly white, had prominent noses, and that the men wore beards. There is no reason to suppose that they were any different racially from the Mediterranean Yemeni highlanders of today.

Without question a careful study of authentic South Arabian archeological specimens, even those removed from their contexts, as all those available are, could do much to solve the problem of the contacts and influences of this civilization. But such a study is yet to be made. From the inscriptions, and from classical and Arabic documents, we may build a second picture—that of the ethnography of these kingdoms; their boundaries in time and space, their social structures, their religious practices, and their economic life. With the aid of the prodigious scholarship of Nielsen and his associates, we will proceed to discuss these in brief.

It cannot yet be determined with any accuracy when the South Arabian kingdoms were first established. It is known, however, that Ma'an was probably the oldest, with Kataban perhaps nearly as old,

while the Sabaean kingdom was, relatively speaking, young. The history of southern Arabia, as an important center of civilization, may have started, however, as early as 1300 B. C. and it continued until the time of Mohammed. A more conservative, but otherwise in no way preferable, date is 900 B. C. Whichever or whatever date one accepts, there can be no doubt that this cultural emergence was preceded by centuries of preliterate, in a sense predynastic, agricultural civilization.

At some chronological point between the two dates mentioned, southern Arabia came into prominence as a highly civilized agricultural region, flourishing near the source of the incense trade route, which went up from the Hadhramaut around the western edge of the Empty Quarter to Mekka, Medina, and the ports of the eastern Mediterranean. It also served as the principal or only route by which goods from India were transhipped and carried overland. This trade position was highly artificial and depended almost wholly upon the suppression of the sea route up the Red Sea. When this was opened, in the second century A. D., the kingdoms of southern Arabia fell, and the country lost its importance to the world.

Of the four kingdoms, Hadhramaut alone produced incense, which also came from Dhofar farther east. The other three lay on the trade route and served as carriers, thereby collecting their "cuts" from the rich trade profits. A tear of incense resin, of negligible value on the tree, had been doubled and redoubled many times in price before it reached the Mediterranean. This ancient racketeering was based upon two sound economic principles, as valid now as then: the first, that of the monopoly, and the second, that of bought protection, in which the Arabs and desert people elsewhere have long been experts.

The Minaean kingdom, which was apparently the oldest, had passed its period of efflorescence before the Sabaean began. It was also the northernmost, located in the Jauf and Nejran, with Ma'an its main city. Nielsen believes that the basic elements of this civilization came from the coastal strip along the northern Persian Gulf, which the Arabs call Bahrain, and the Babylonians called Magan. According to Nielsen, Ma'an=Magan, with the 'ain substituted for the Babylonian G.

There were 20 Minaean kings, covering, in their combined reigns, a period of at least 600 years. The older estimate would place the Minaean period from 1300 to 700 B. C.; the younger, from 900 to 300. If the alphabetic inscriptions from Ma'an go back to the oldest period, then the younger dating is the more likely, since, in the Sinai region and northern Arabia, alphabetic writing does not antedate the first millennium. The age of the Katabanians is also in doubt, but in all probability their kingdom was roughly contemporaneous with that of

the Minaeans. At what time Hadhramaut changed from a trade depot to a kingdom is not known.

The Sabaeans appear toward the end of the Minaean reign, perhaps, as Nielsen suggests, from the northern Arabian Jauf. They were perhaps also camel nomads, who carried the trade for the Minaeans, and who, later having decided to take their share of the business directly, established a domain in the south, grafting themselves on the northern portion of what had been Katabanian territory. There are two Sabaean periods: the earlier, called the Mukarrib period, in which the king bore the title *mukarrib*, which indicated a primarily priestly office, and a later, in which he is called *malik*, the common Semitic word for king. A parallel transition took place in Kataban. The exact dates of these two periods are unknown, depending on a floating correlation. For the first Nielsen offers 1115–815 B. C., 950–650 B. C., and 815–510 B. C., of which he prefers the middle one. This, of course, goes with the early dating for the Minaeans.

The most important Mukarrib of Saba was Kariba-Ilu (the Priest of the God Il), who killed 4,000 men in a war against Kataban, then turned on Ma'an and killed 45,000 while taking 63,000 prisoners and 31,000 head of cattle. At the same time his army laid the Nejran country waste, destroying the Minaeans forever. Two Assyrian inscriptions, dated 715 and 685 B. C., respectively, serve to locate this Kariba-Ilu accurately in time. He gave presents to King Sargon of Assyria, although he was in no sense a vassal of the latter monarch. The difficulty in pinning the entire chronology to him is that there were several kings named Kariba-Ilu, and it is not yet known which one of them was the great conqueror and Sargon's friend.

At any rate, this Mukarrib period was the period of rise and efflorescence for the Sabaeans. They established themselves definitely as the principal people in southern Arabia; for after destroying the Minaeans and crippling the Katabanians and Hadhramautis, they turned to offer these two latter peace and alliance, which must have implied a Sabaean hegemony. The material high point of this period was the erection of the great dam at Marib, which provided irrigation water for the whole section.

From about 650 to 115 B. C., according to Nielsen's correlation, the Sabaeans continued to be the dominant people in the incense and Indian trades. This was the Malik period. In 115 B. C. their nation became the dual kingdom of Saba and Dhu Raidan, with rival families arising; the Hamdanis, of whom there is still an entire tribe in Yemen, and the Himyarites, who were only a single noble family, although their name has erroneously been preserved as the title of the whole South Arabian civilization. The Hamdanis were centered at Marib, the Himyarites at Dhu Raidan. From 115 B. C. to A. D. 270 these

two families jockeyed each other about in their struggle for exclusive power.

The later history of southern Arabia, until the arrival of Islam, is relatively well known. In 24 B. C. Aelius Gallus led an expedition to conquer this whole section, known to the Romans as Arabia Felix, but the Romans never got there. Somewhere in the sands near the Nejran the majority of them perished, and those who survived at this point turned back. About A. D. 270 the Axumite Ethiopians conquered Arabia Felix and ruled it—they were Christians and set up bishops and bishoprics. But by A. D. 378, apparently, their rule had come to an end. The Axumites themselves were the descendants, in whole or in part, of earlier emigrants from the Hadhramaut, who had carried Semitic civilization to Ethiopia and there become Christianized.

In A. D. 449 and 450 the dam at Marib burst twice, washing out the valley and ruining agriculture, and at this time there must have been a mass exodus. Perhaps it was at this time that the region of Sana'a became the nucleus of Yemen. The later kings, who ruled before the bursting of the dam, were in many instances Jewish in religion, and the strong Jewish colony of Yemen had before then been founded. In A. D. 525 the Ethiopians returned, and in A. D. 570, the birth year of Mohammed, the Ethiopian viceroy Abraha, who ruled Yemen, organized an expedition, mounted on elephants, against Mekka. This expedition soon came to grief, however, and in the same year the Persians conquered the country. In A. D. 628 the last Persian governor became a Moslem, and Arabia Felix was ruled from Mekka. By the time of the establishment of Islam in Yemen, southern Arabia had lost its earlier importance. This was due to the break-up of the overland trade, caused chiefly by the establishment of ports along the coastal Tihama by the Ethiopians. Before this time we hear little of the coastal plain—it was ethnically a different country, as it is today.

About the political and social organization of the four southern Arabian states, we have sufficient information to permit the reconstruction of at least a plausible if striking system. Since each of the four was organized in essentially the same way, it will suffice to describe the functioning of the best known, Saba. Here society was graded and subdivided on two interlocking bases, kinship and inheritable rank. These divisions were formally expressed by the presence within the state of several parallel tribes and four graded classes. The tribe was both a kinship grouping and a geographical expression; each tribe except one was a completely parallel unit, which included members of the three lower classes, in approximately equivalent proportions. The one asymmetrical tribe possessed in addition the entire personnel of the highest class, small in number, and including the priest-king and his near kinsmen.

The state was named after the leading tribe, and the capital was situated in this tribe's territory. The king was the representative of godhead on earth, the chief diety which he represented was the national god of the state, although each tribe kept its own tribal divinity as well. The leading tribe was concerned with the maintenance of the main temple and of shrines; thus, the leading tribe maintained its political ascendancy through a religious sanction.

Each tribe was bound to a certain section of land and was responsible for the agricultural success of this allotment. The members of the tribe were obliged to remain on this land and could not farm elsewhere—there was no freedom of movement from the agricultural and residential standpoint. For political purposes, the tribe was subdivided laterally into thirds or quarters, and tribes could be recombined arbitrarily for political purposes. In this way the genealogical solidarity of the tribe could be broken down and must eventually have become secondary to the geographical tie. This organization into tribes and subtribes made it easy for the government to levy armies and collect taxes, and also to provide for the poor.

Local landholders, belonging to the upper tribal class, were also war leaders and were responsible for the raising of *covées* to execute public works, particularly irrigation projects, and to maintain the highway along which the precious frankincense traveled. Furthermore, these tribal leaders were charged with recruiting warriors and overseeing agriculture; for if any lands were neglected or poorly farmed, the tribal overlords were held responsible.

The three social classes, aside from the divine upper crust, are designated by the as yet vowel-less words *Mawd*, *Ksdn*, and *Dmwt*. For the sake of simplicity, we shall designate these by the numbers 2, 3, and 4, leaving number 1 for the royal caste. Number 2 was a privileged class of landowners, with the feudal rights mentioned earlier; number 3 formed the most numerous group, consisting of free landholders, the owners of small, individual properties, who provided the bulk of the working power. They were farmers, paid a land tax, did military service, and submitted themselves to the feudal authority of the noble families of the second class. Members of class number 3 were further subgraded into categories by occupation, since they apparently included in their numbers the skillful artisans responsible for the high level of South Arabian material culture. If the modern parallel in Yemenite society reflects an earlier condition, then the farmers proper must have been superior socially to the artisans. The members of class number 4 were landless serfs, without political freedom. It is not known whether or not they fitted into the genealogical scheme upon which the tribal structure was erected.

An officer called *Kebir*, in Greek *πρεσβύτερος*, presided over each tribe as head. The name itself implies that he was originally an elder, and that his position was determined by family precedence. His office was partly priestly, perhaps in the earlier stages of South Arabian social evolution largely so. It was he who brought sacrifices to the tribal temple and offered them to the tribal god.

Besides the lands governed by the tribal princes, there were crown lands governed directly by the king, and the occupants of these territories paid him taxes and military services. Presumably these were the lands occupied by members of his own tribe. Much of the land also belonged to the temple; on it were priestly colleges, each with its *Kebir*. Thus, the prototype of the modern *zawiya* and its sheikh or fakih existed in pre-Islamic Saba. Every member of society, of whatever class, was obliged to do some work on the temple lands, and the gods were offered sacrifices, *ex votos*, and the tithes of all produce. The temples themselves were built with money given or bequeathed as offerings to wipe away specific sins committed by the donors.

The dual system of national partitionment, vertically into tribes and horizontally into classes, produced a state held together by religious sanction and by a specialized common economic purpose. Exactly how the caravans were organized, and who had control of the road taxes, we do not yet know, but the technique must have fitted into the system already described.

One can find a number of parallels to this tightly integrated and overtly stratified form of organization, in various parts of the world. The Inca system in Peru was basically similar, and that of the Aztecs was, at the time of Cortez, assuming a similar form, while the germs of such a system may be found in the tribal organization of the Muskogean peoples of the southeastern United States. In the Old World, the Sumerian and Babylonian systems were not radically dissimilar. In Egypt the divinity of the king and the role of the nomes and nomarchs might be considered parallel. The caste system, with occupational segregation, has its parallels in India, and may there go back to the time of the Indus Valley civilizations. Thus the technical perfection of the South Arabian state, as exemplified by Saba, is not surprising, and its form relates it to the whole string of civilized communities reaching from the Nile to the Indus.

But like all other systems, no matter how perfectly adjusted, it was susceptible to change. As the Sabaean power grew through military conquest, the importance of the military element naturally increased. A subcaste, called by the consonantal sequence *'Khms*, arose from the middle class, to parallel the *Kshatrias* in India; this was a strong military caste, which came in later periods to cut across tribal lines, and developed into a strongly unified group which wielded great political

power. Its rise was perhaps comparable to that of the Nazi party in modern Germany, whose beginning was both middle class and tinged with military concepts. Needless to say, the rise of this fascist military class was entirely a Sabaeen phenomenon; the power and initiative of Minaeans and Katabanians had declined long before its inception, and we know too little about the kingdom of Hadhramaut to make comparisons in that quarter.

The Katabanians, as a matter of fact, were more democratically governed than the Sabaeans, for each tribe had a council or assembly of landowners; this was distinct from the parallel council of noblemen; thus, the Katabanians had a bicameral parliamentary government, with a House of Lords and a House of Commons, with the king in the supreme position, over both. This system may well have been the early political formula of all of the South Arabian states, lasting through the Mukarrib period in Saba, and replaced during the Malik period by the feudal system above outlined, eventually to be thrust in turn into the shade by the rise of the military caste, and of the rival warring families of Himyar and Hamdan.

The religion of these southern Arabian states, so intimately entwined with the social and political structure, is not easy to reconstruct. Moslems are notoriously loath to preserve traditions of earlier paganism and like to garble what pre-Islamic history they permit to survive in anachronistic terms. Our religious sources, then, are confined to the body of inscriptions so far published, and a few superficial Greek observations. Although to competent Arabic scholars the reading of the southern Semitic inscriptions is not difficult, since the alphabet may be learned in a few hours, and the grammar and vocabulary are basically the same, the knowledge of this writing passed out of common circulation soon after the Islamic penetration brought a new Semitic speech and a new alphabet. In the tenth century Abu Mohammed el Hamdani could still read the old inscriptions, so we know that the knowledge had not, in his time, completely died. He wrote 10 books about the olden times, of which only 2 survive.

The inscriptions consist largely of the names of gods, of which over a hundred are known. Many of them are attribute names, such as *Wadd*, love; *Sadik*, truth; and *Rahman*, the Compassionate, which passed over into Islamic terminology. Besides these are a number of animal names: the bull, the horse, the ibex, the snake. Others are kinship terms: father, paternal uncle, brother, mother, etc. Still others symbolize the omnipotence of the god: *Ba'al*, the ruler; and *Malik*, the king. Personal names of individual men are often of the "Slave of the Compassionate" type, the pre-Islamic prototype of 'Abd er-Rahman, and similar dedicatory terms. There is again a

class of god names which indicate tribal affiliation, the protector of such and such a tribe, or paternal uncle of such and such a tribe.

Needless to say, this multiplication of god names does not imply an extensive polytheism. All the names, all the gods, have been reduced to three: the Sun, the Moon, and the Venus Star. These are respectively represented in sculpture as a disk, a crescent, and an eight-pointed star. Each of these three had many functions and attributes, each with a name, and the reduction of these to three is only exceeded by the Islamic heaping of all attribute names on a single divinity. Although there were but three gods, each might be worshiped separately in different aspects and under different names; thus the tribes were still able to possess personal divinities. The state god of the Minaeans was *Wadd*, that of the Kutabanians *ʿAmm*, that of the Hadhramis *Sin*, and of the Sabaeans *Il Mukah*. All were the moon.

There were no carved images of these three—the Semitic tabu against graven images, while by no means generally applicable, was in force in regard to the divinities themselves. What images we find are of people. These gods, however, had perches or resting places, in the form of crude stones, such as the Ka'aba itself. The sun was a woman, and the moon her husband. Once a month, at the time of conjunction, they had sexual intercourse; the stars are their children, and of these Venus is the most important. These stars eventually became angels; people and animals are also the children of the gods. Thus, a direct kinship connection exists between this divine trinity and mankind, with the head of the state acting as the symbol and concentration point of godhead in man.

Among the northern Semites the sun was the most important, as the promoter of fertility in vegetation; in southern Arabia, where the sun is too hot for comfort, and scorches and withers, the night is the time of coolness, and, in the moonlight, the time for travel and work. Nomads travel much at night, and the moon with its phases gives them their yardstick for measuring time. Thus, whereas the sun was the important god to the northern Semites, the moon was supreme among the southern groups, including not only the southern Arabian peoples, but also the pre-Islamic Arabs proper, who lived farther north in the peninsula.

The god *Il* or *Ilah* was originally a phase of the Moon God, but early in Arabian history the name became a general term for god, and it was this name that the Hebrews used prominently in their personal names, such as Emanu-el, Isra-el, etc., rather than the Ba'al of the northern Semites proper, which was the sun. Similarly, under Mohammed's tutelage, the relatively anonymous *Ilah* became *Al-Ilah*, The God, or Allah, the Supreme Being.

We know comparatively little about the technique of sacrifice employed in worshipping these divinities. The temple was the great economic nucleus of each tribal region, with sovereignty over its own grounds and fields, and it was ruled by its head priest with his troop of acolytes. To it came worshipers bearing votive offerings, little statuettes of gold in the forms of animals and men, brought to the god as instruments of supplication for future favors and as rewards for intervention in response to a previous oath. Models of arms and legs represent the divine curing of these limbs. A Greek source of the fifth century A. D. states that the Himyarites sacrificed the choicest of their war booty in the early morning light, to Venus in his role of Morning Star. The most important sacrificial victims were the handsome young boys who had been led to the temples as prisoners. The same source also informs us that other tribes worshiped Venus in the role of the Evening Star, an old man, and consequently rendered him old men in sacrifice.

It is possible, as Nielsen has done, to fit this whole religious system, as we now know it on the basis of incomplete evidence, into the general Semitic scheme, in which the four kingdoms of southern Arabia, and the northern Arabs as well, become the southern branch, and the Phoenicians, Babylonians, Assyrians, etc., the northern, with the Jews playing a mixed role. Whatever the findings of the learned school of southern Semitists in Denmark and Germany, we must, as these scholars would agree, still await excavation and a thorough stratigraphic and typological study of remains on the spot before any of the problems, religious or otherwise, which concern this civilization may be finally settled.

For the present purposes it must be considered sufficient to have presented the foregoing brief and unscholarly resumé of the work of Nielsen and his associates, as a summary of present knowledge of this intensely interesting and important archeological problem. But even the short newspaper account of Philby's journey, and Hellfritz's uncritical hegira, as well as the observations made from the air by the French aviators who, in 1935, flew over some as yet unidentified city, furnish their contributions, as does the equally uncritical inspection of the Imam's Museum made by the author.

We know now that the influence of the late classical world on the Sabaeen kingdom cannot be overemphasized. Greeks or Byzantines must have been imported to the Sabaeen state to make statues and carve stone. In earlier periods, Egyptian and Mesopotamian influences were equally important. The South Arabian cities were commercial metropolises of a cosmopolitan character, grafted on a simpler agricultural state, in which imported goods and styles probably were more important than those which were more nearly indigenous.

This cosmopolitan character is revealed by the nature of the objects found in Sabaeen sites, many of which are too large to have been imported and must have been made by traveling workmen. Other things revealed by recent findings are Philby's discovery that Shabwa itself, although flanked by residential suburbs, was a small, walled-city nucleus, scarcely 300 to 350 yards square, in contradiction to Pliny's statement that the city alone contained 60 temples. We now know for the first time that the salt deposits at Shabwa, which are still worked, formed a major incentive for the location of the city at that spot, and that prosaic salt shared the trade with the more romantic frankincense and myrrh. We also know that Marib is surrounded by submerged volcanic craters, which, Philby suggests, may have erupted at about the time of the destruction of Pompeii, thus weakening or breaking the famous dam. Through the diligence of this same explorer, we are introduced to a new city site, Ukhdud, in the Wady Nejran, a step farther north from the Minaean center, and the seat of a bishopric in Christian times.

Much remains to be done. The field of southern Arabian archeology is about to open. Let us hope that its miraculous preservation past the period of trial and error in archeology elsewhere may permit slow and careful excavation by properly qualified persons, trained in adequate techniques. Let us further hope that the princes and kings who control these sites will continue to be well advised and will refuse permits to the sensational and the incompetent, following the policy so ably expressed by His Excellency Raghib Bey, Foreign Minister of Yemen, who feels that some important remains should be preserved for the archeologists of the future, who will have developed techniques of obtaining scientific information unknown today.

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THE NEW WORLD PALEO-INDIAN¹

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[With 12 plates]

Scattered finds in North, Middle, and South America over a period of years have added materially to the growing body of evidence for an occupation of the Western Hemisphere in reasonably ancient times by peoples who, judging from their physical characteristics, migrated from northeastern Asia and became the basic aboriginal population of the New World. In comparison with the remains of later periods, traces of the early Indian are far from numerous. They are sufficient, however, to demonstrate that more than chance occurrences are involved and to justify the belief that further investigations will increase knowledge about this phase of the pre-Columbian history of the Americas. To name and describe all the discoveries pertaining to this subject (Sellards, 1940) is beyond the scope of the present paper. It is possible to discuss only a few of the recent and more important finds and to consider their bearing on the problems of age and general cultural status.

NORTH AMERICA

Beginning in 1926 and continuing through subsequent years a series of discoveries in North America yielded evidence, now generally accepted, for a comparatively early occupancy. These finds consisted of associations between stone artifacts and the bones from extinct species of animals, of stone implements and hearths occurring in strata of identifiable geologic age, of camp sites located along old terraces and on the shores of lakes long since dry, and of human bones incorporated in deposits of geologic significance. The materials from several of these occurrences seem to be components of complexes from the same or related cultural groups. In other cases the collections are from single sites which appear, in the light of present information, to have no connection with those found elsewhere. The evidence derived from comparable artifacts occurring under similar conditions at different loca-

¹ Revised, with the addition of some new material and illustrations, from the article "Evidence for a Paleo-Indian in the New World," in *Acta Americana*, vol. 1, No. 2, April-June 1943.

tions is more convincing, of course, than that coming from only one. A number of the thus far unique discoveries, however, have contributed valuable information.

The most widely distributed and probably the best known is the Folsom Complex (Howard, 1935; Roberts, 1935, 1939). The original find in this category was made near, and took its name from, the little town of Folsom in northeastern New Mexico. The Folsom Complex consists of a variety of stone and bone artifacts occurring in deposits indicative of some antiquity and in association with bones from extinct species of animals or from forms not now living in the regions where the finds are made. Three types of implements, the projectile points and two kinds of stone knives, are characteristic and may be considered criteria for the complex. The additional varieties of stone tools generally found accompanying those three types also occur in other complexes and for the most part are too ubiquitous both in time and space to have significance. The points and one type of knife (pl. 1) are characterized by facial fluting. There are longitudinal channels on each face, extending from the base toward the tip, which produce lateral ridges paralleling the edges of the blade. The second type of knife, made from the flakes removed when the other forms were fluted, is a long, thin, plano-convex blade with approximately parallel sides. The knives and one series of the fluted points were given a fine, secondary chipping along the edges after the channel flakes were struck off the faces of the blade.

Other points, although fluted, tend to be more generalized in character (pl. 2). They do not show as careful workmanship, do not have the peripheral retouch, and are larger. The relationship between the two forms and the reasons for their differences have not yet been determined. Various explanations have been suggested. One is that the larger forms represent an early development of the type. Another takes the view that they may be a degenerate and later survival of the better-chipped form. Still different is the idea that they were used in killing large animals. Also, there is the possibility that they indicate a borrowed technique in the method employed in the manufacture of points, a technique that was never fully mastered by those who took it over. Any one or all of these postulations might apply in greater or less degree under varying circumstances. Definite statements, however, are not warranted without specific proof. The purpose of the fluting can only be surmised. It would facilitate hafting, make for easier penetration, would probably stimulate bleeding in a wound, and would tend to promote an inward working of the point if it was broken from its shaft. The makers may have had these or some other end in mind. That it was functional rather than notional seems likely because the fluting weakened the point

and made it more liable to breakage, hence would not have been done without good reason.

Animal bones with which Folsom implements frequently are associated are those from bison, the mammoth, large American camel, antelope, extinct and living forms of the musk ox, giant sloth, and the native horse. The mammoth, sloth, camel, horse, antelope, and kinds of bison represented are no longer in North America, and the living type of musk ox is now far north of the area where the archeological specimens are found. Bones from animals still present in various parts of the country also occur in Folsom sites. In this group are rabbit, fox, wolf, deer, and pronghorn, species that have changed so little over a long period of time that they have no bearing on the problem of relative age. Some of the sites also contain invertebrate fossils as well as mammal remains. Included in this material are species that either are extinct or no longer live in the districts where such assemblages occur. Wood, in the form of charcoal, found in hearths and accompanying the bones has a similar status. There is good indication of a climatic change and the lapse of an appreciable length of time in these mammal, invertebrate, and charcoal remains from species normally found in a colder and moister environment than that prevailing today.

Good geologic evidence to augment that from the fauna and flora was obtained from the excavations in three main Folsom sites. The animal bones and artifacts at the original location in the northeastern corner of New Mexico (pl. 3) came from a stratum of dark clay containing gravel lenses and small concretions of lime, a deposit left by an old bog or water hole. Extending several feet above this layer were sediments consisting of highly restratified earth that have been identified by some geologists as belonging to the close of the Pleistocene or last ice age and by others as representing early Recent. All agree, however, that their age closely approximates the transition between the end of the Pleistocene and the beginning of the Recent. In the Black Water Draw between the towns of Clovis and Portales, 180 miles south of the Folsom site in eastern New Mexico, the assemblage of bones and cultural material is found in a bluish-gray deposit that is believed to be the bottom of old lake beds that correlate with the high-water stage of ancient Lake Estancia located some distance farther west (Howard, 1935; Antevs, 1935a). General opinion is that Lake Estancia was at its maximum during a pluvial period when there was much heavier precipitation and temperatures were lower, an era corresponding to the final stage of the Pleistocene, and the bones and implements are regarded as dating from that time. At the third site, the Lindenmeier, north of Fort Collins in northern Colorado, the situation is somewhat different. At that

location the remains occur in the deposits of a vestigial valley bottom that has taken on the appearance of a terrace as a result of the eroding of the ridges that once bordered its southern side (pl. 4, fig. 1). By correlating the occupation level, which is in the bottom of, or just below, a dark-soil zone that was formed during a wet cycle (pl. 4, fig. 2), with the terraces of the main drainage streams, and those, in turn, with traces of glacial stages in the mountains on the west, it was demonstrated that the period of the archeological remains was near the close of the Pleistocene (Bryan and Ray, 1940). Approximately the same geologic horizon is indicated in all three cases and this is corroborated by evidence from several smaller sites. As a consequence the belief that the Folsom Complex developed toward the end of the Pleistocene or late glacial period and carried over into the beginning of the Recent is now more or less generally accepted.

A majority of the Folsom remains and sporadic traces of the complex are found in the eastern part of the continent. Some have been reported from the Great Basin—the plateau area comprising western Utah, most of the State of Nevada, and southeastern California—lying between the Wasatch Mountains and the Sierra Nevadas, and a few points have been found in northern California where there is one possible small site. Most of the material, however, is in the area extending from Alberta and Saskatchewan in Canada on the north to southern New Mexico in the south, from the eastern slopes of the Rocky Mountains on the west to an eastern border that follows roughly the western boundary of the Dakotas, cuts across western Nebraska, Kansas, Oklahoma, and thence into Texas, where it turns eastward to the Mississippi River. There are indications of smaller centers in the region around the junctures of the Missouri and Ohio Rivers with the Mississippi, in Ohio, western New York, western Pennsylvania, Virginia, Tennessee, Georgia, and northern North Carolina. An old medicine man in Sonora, Mexico, is reported to carry two such points in his bag of fetishes. There is no information, however, on how he obtained them or where they were found, and they have no value as evidence. The distribution of Folsom implements implies that there must have been some specific relationship between the physical environment, the hunting economy basis of the cultural pattern, and the period when the spread took place. The latter will be considered in subsequent discussion, as it also has a bearing on some of the other types of remains.

Papers pertaining to the general subject of the Paleo-Indian frequently link another group of points with the Folsom series (pl. 5, fig. 1). They are called Yuma from the county in eastern Colorado where the first examples were found. The two forms were at first

believed to be related because they were observed lying together where the clay substratum had been exposed by the blowing away of the surface soils. One typological study based on this material derived the Folsom type from the Yuma, while another concluded that the Yuma was an outgrowth of the Folsom. As a consequence the terms Folsom-Yuma and Yuma-Folsom were used for a time. They have been dropped by most writers, however, because subsequent investigations have shown that the two types are from different complexes. The early forms of the Yuma may have been contemporary with late Folsom types, but their main development was in subsequent periods. As a matter of fact they continued to be made in some regions until almost historic times. Because of this it is obvious that Yuma-type points are not as significant as was previously supposed, and their presence in a collection may mean little from the standpoint of age.

Sandia Cave (pl. 6), located in the Sandia Mountains northeast of Albuquerque, N. Mex., has contributed further evidence on the Folsom Complex and in addition contained materials that put it in the category of an individual or unique type of site. Three different assemblages of bones and artifacts were found in distinct levels in the cave (Hibben, 1941). One includes cultural objects that are probably pre-Columbian in age, yet are comparatively recent in origin. The second series consists of specimens from the Folsom Complex, and the third group is composed of artifacts that have been called the Sandia. The top stratum or upper floor level contained the recent specimens. This layer of dust, bat guano, pack-rat dung, and trash rested on a hard crust of calcium carbonate that entirely covered and sealed in the underlying deposits. Beneath this "floor" was a layer of cave breccia containing the Folsom artifacts and bones from bison, mammoth, giant sloth, camel, native horse, and wolf. Below the breccia was a stratum of yellow ocher in which were neither bones nor artifacts. Underlying the ocher was another deposit of cave breccia similar to that above. The Sandia type implements and bones from bison, camel, mammoth, mastodon, and horse came from this layer. On the original floor were hearths. One of them was outlined with small, rounded stones that must have been carried from the canyon below because they were the only stones of that type found in the cave. Charcoal, ashes, and fragments of burned bones filled the hearths, and alongside the stone-encircled one was a Sandia point.

Typical Sandia points, the most characteristic artifact in the complex, are readily recognized because they have a notch at the base on one side only (pl. 5, fig. 2). There are two main forms with gradations between that in some cases are difficult to assign to either category because of their intermediate nature, but all have the basal

notch. Sandia type 1 is lanceolate or rounded in general outline, has a convex base, and is lenticular in cross section. Sandia type 2 tends to be more elongated with parallel sides, straight or slightly concave bases, an occasional basal thinning produced by the removal of a short flake suggestive of an incipient Folsom fluting, and a diamond-shaped cross section. Single-notched points of the Sandia types are not common in North America and only rarely are observed in collections, principally in those from the southern plains area. An example of Sandia type 2 was found early in 1944 weathering out of a gravel layer near Abilene, Tex.,² in a district where there are deeply buried sites that have yielded artifacts comprising another complex that is regarded as being fairly old. The latter will be considered in some detail in subsequent paragraphs and need not be discussed further at this place. The Sandia forms are suggestive of the well-known points from the Solutrean industry in the Old World—in fact both types have analogs there—but probably were not derived from, or related to, them. Besides points, the Sandia Complex includes stone knives, scrapers, pieces of large blades, and a number of grooved stone balls. The knives and scrapers differ little from comparable implements found in the cultural materials of other hunting peoples, but the stone balls are particularly interesting because they suggest the bolas of South America. The latter, attached to the ends of a thong or cord, are hurled at animals for the purpose of entangling and catching them. If used for a similar purpose by the inhabitants of Sandia Cave, they indicate a new trait in North America, one that apparently was short-lived and very restricted in its distribution.

Where there is no direct physical connection between the deposits in a cave and those of known geologic age in the surrounding terrain, it is difficult to make correlations, and conclusions regarding their relationship may be questioned. Indications are that the breccia of the Folsom and Sandia layers and the intervening yellow ocher must have been formed when there was much more moisture in the region than has been known in recent times. The fauna, represented by the bones, is characteristic of a cooler climate. Since cool, moist conditions prevailed throughout this area in the pluvial period following the maximum of the Wisconsin glaciation and the combination has not occurred in sufficient degree to produce comparable phenomena in the intervening millennia, it seems probable that the cave was occupied at that time. Evidence from the Folsom sites, as previously mentioned, is for a late or terminal Pleistocene horizon, and it is logical to suppose that the Folsom material in Sandia Cave would be of similar age. The Sandia artifacts, underlying the Folsom as they did, would be somewhat older yet belong to the same general period.

² Information contained in a personal communication from Dr. Cyrus N. Ray, the finder.

Gypsum Cave (pl. 7, fig. 1), in the Frenchman Mountains east of Las Vegas, Nev., also contained material of significance (Harrington, 1933). Several cultural horizons were represented in its deposits. In the top layer were materials attributed to the modern Paiute Indians. Below it were two levels in which were articles left by groups related to the Pueblo peoples of pre-Columbian times. These strata rested on a sterile layer indicative of a break in the occupation of the cave. In the deposits beneath the sterile bed were archeological specimens, quantities of sloth dung, bones from the giant sloth, an extinct species of wolf, three species of camels, and the native horse. The evidence appeared to demonstrate contemporaneity between the makers of the artifacts and all the animals except the horse. Although there was some doubt about the latter, those making the investigations expressed belief that the animal still survived in the region when the cave was occupied by men and that they were more or less acquainted with it even though they apparently did not hunt it. This opinion was predicated on the fact that projectile points similar to those obtained from the cave, long triangular-shaped blades with square shoulders merging into a stem that tapers into a rounded or pointed base (pl. 7, fig. 2), are found in open sites in western Nevada in strata that also contain horse and camel bones. Subsequent discovery of the same type points in a layer of horse dung in a cave (Etna Cave; Wheeler, 1942) about 100 miles north of Gypsum Cave considerably strengthens the argument and indicates that the original assumption was probably correct.

There is some difficulty, as in the case of Sandia Cave, in dating the material from Gypsum Cave. In the bottom levels were water-borne deposits in which were camel and horse bones. Above them were silts left by standing water. The top surface of the latter gave evidence of a period in which there was considerable evaporation, and in places it was solidified by mineral substances that had been carried in solution. The earliest traces of the giant sloth were found on this surface and in places they were partially covered by a stalagmitic formation. From that level to the top of the deposits the strata were wholly dry and gave every indication of always having been so. The artifacts and other evidence of human occupation were found only in the dry layers. Botanical specimens obtained from the latter represent an arid flora comprising plants that are present in the region today, although some of them live only at higher elevations. The water-deposited layers, because much moister conditions than have prevailed at any subsequent period would be required to produce them, have been correlated with the last great rise in the level of ancient Lake Lahontan in Nevada. This is believed to have taken place during the pluvial stage mentioned in the discussion of the Folsom

and Sandia remains. As the era of aridity had already set in before the arrival of the hunters, even though their appearance was comparatively soon after its beginning, the initial occupation of the cave is believed to have taken place early in the Recent period.

Evidence for a relatively ancient group in southern Arizona was found in Ventana Cave (pl. 8) in the Castle Mountains (Haury, 1943). There in the bottom of approximately 15 feet of deposits were stone implements accompanying bones from the native horse, giant sloth, tapir, and bison. The artifacts were projectile points, choppers, scrapers, and graters, a complex very similar to the Folsom except that the points were not fluted. They approximate the general Folsom shape, but no attempt was made to produce the facial channels (pl. 9, fig. 1). The assemblage of bones and artifacts was in a lime-cemented layer of volcanic debris. This conglomerate, supplemented by other indications of water action, is good evidence for a decidedly wet period in that part of the Southwest. The combination of heavy precipitation and an extinct fauna again suggests a pluvial condition comparable to that previously discussed and, although geologic studies at the cave have not yet been completed, possibly a terminal Pleistocene or beginning Recent age.

Important evidence bearing on later developments in the area was also found in Ventana Cave. Artifacts in the layers above the stratum containing the old material trace the progress of a cultural development from a simple hunting, food-gathering economy through the acquisition of agriculture and the pottery-making industry and subsequent agricultural and ceramic stages to historic times. The strata containing this series rested unconformably on the conglomerate, indicating a break in the continuity of occupation. The hiatus probably represents a fairly long interval because during that period modern fauna replaced the old animals and there was marked change in the types of cultural objects.

Recent erosion and the cutting of gullies or arroyos in the southwestern corner of New Mexico, in southeastern Arizona, and in the adjacent area just across the border in northern Mexico have exposed hearths, artifacts, and other traces of human habitation. The materials from these sites have been called the Cochise Culture and have been grouped into three stages or sequent phases on the basis of their typological traits, the nature of their geologic provenience, and the associated fossils (Sayles and Antevs, 1941). The oldest of the phases occurs in sand-gravel deposits that also contain bones of the native horse, camel, bison, mammoth, and extinct wolf, pronghorn, and coyote. Hickory charcoal is found in the same level. This kind of wood no longer grows in the region as it requires much more moisture than is now available. The layer of sand and gravel has been interpreted as being a flood-plain deposit from a permanent

stream, and this also points to the need for much heavier precipitation. Study of the general area indicated that only during the last pluvial was it wet enough to support the growth of hickory and to supply water for such a stream. In combination with the remains of extinct animal forms this factor again implies a terminal Pleistocene age for the artifacts. Most of the latter are grinding or hammering stones; there are only a few knives and scrapers and no projectile points. The absence of points is somewhat puzzling. It is possible that bone or hard wooden points were used and that these have not been preserved in recognizable form or have completely disappeared. From present evidence it seems that the culture had an economy based on food gathering. In the subsequent stages more flaked implements were made, and there is some indication of a certain amount of hunting. The second and third stages fall in the Recent period and material from them correlates closely with that in the levels in Ventana Cave lying between the disconformity and the upper strata containing the recent remains (Haury, 1948).

Implements from Pinto Basin and Lake Mohave, in the desert area in southern California, practically duplicate those in the upper levels of Ventana Cave and the later stages of the Cochise. Lake Mohave and Pinto Basin are formations attributed to the pluvial of late Pleistocene times, and artifacts are found along their old beach and shore lines. From this it has been suggested that the implements must have been contemporaneous with the ancient lakes (Campbell, 1935; Symposium, 1937). Because this material is mainly from the surface, and in view of the fact that similar artifacts in the Cochise Culture and Ventana Cave are definitely Recent, it does not seem that they should be considered evidence for an early occupation of the district. That people actually were in the California desert area at approximately the same time as those who made the artifacts present in the bottom of Ventana Cave seems probable, however, as sporadic occurrences of implements suggestive of the Folsom Complex are found there and one supposed Folsom site has been reported although there are no data on it thus far.

In north-central Texas deeply buried occupation levels (pl. 9, fig. 2), hearths, and graves in the banks of various streams and their intermittent tributaries yield information and specimens that suggest relatively early inhabitation of that region. The oldest appears to center in the Abilene district, where there are a number of stratified sites in which different types of artifacts are found at depths ranging from 4 to 30 feet beneath the surface (Ray, 1930). In the lowest levels are charcoal, crude tools of the heavy scraper, hand-ax, and chopper types, and thick leaf-shaped points thinned at the base by the removal of a broad, short flake from one side. This treatment is suggestive of that

noted on some of the Sandia type 2 points. There may be no relationship between the two forms, but it is interesting to note that the Sandia type 2 point found near Abilene apparently belongs in the same horizon as the Abilene type. In the deposits above occur a variety of implements and a sequence of point types that are considered components of a single complex, one that has been named the Clear Fork (Ray, 1938; Roberts, 1940, pp. 74-76). The upper strata produce artifacts attributable to the Texas Indians of late pre-Columbian times.

The implements of the Abilene Complex are found in the top and along the deeply weathered surface of an old soil or gumbo profile and in the bottom of an overlying series of silts laid down by widespread, successive, slack-water sheet floods. The Clear Fork Complex, beginning above the Abilene horizon, occurs in these same silts and shows progression from level to level toward the surface. The gumbo profile has been identified as Pleistocene. The first tentative conclusions were that it possibly correlated with the Illinoian glacial substage (Leighton, 1936), but subsequent evidence suggests that it was more likely mid-Wisconsin or even later in the period. The lower strata in the silts are regarded as belonging to the end of the Wisconsin substage and grading into the beginning of the Recent, whereas the higher levels are definitely Recent. Abilene and fluted points of the generalized type occur in the same horizon, and the smaller, better-made Folsom projectiles are found in association with older forms of the Clear Fork Complex. In addition, fossil mammoth, extinct bison, other vertebrates, and Mollusca remains—generally considered as representing a Pleistocene fauna—come from the same levels. Hence it seems that in this area there is further evidence for a late Pleistocene or possibly slightly earlier occupation.

Various archeological finds of greater or less significance relating to this general problem have been made in other parts of Texas, in Kansas, Nebraska, Wyoming, Utah, Oregon, northern California, Minnesota, parts of Canada, and Alaska (Roberts, 1940; Sellards, 1940), but space limitations prevent their consideration. In the main they tend to corroborate the evidence from the discoveries already discussed.

NORTH AMERICAN SKELETAL MATERIAL

Human skeletal material from the older horizons is relatively rare, and the information furnished by it is not as satisfactory as that from the cultural objects. This is in large part attributable to the fact that antiquity must be determined by the geologic age of the strata in which the skeletal remains occur rather than by the morphological and metrical features of the bones themselves. Associated

archeological and paleontological objects are an important aid, although they also may frequently be inconclusive. The types of men responsible for the Sandia Cave, Folsom, Ventana Cave, Gypsum Cave, and similar complexes are not known, as no human remains have been found in association with implements from any of those cultural patterns. A skeleton sometimes thought of as a possible example of Folsom man was discovered in a bank of the Cimarron River in northeastern New Mexico some 16 miles east of the original Folsom site. The bones were in a water-borne deposit 13 feet 6 inches below the present surface and, from the degree of their fossilization and a tentative correlation between their situs and a nearby buried stream bed and the latter with the bison quarry, were believed to be as old as, if not older than, the artifacts and animal bones at that location (Figgins, 1935). This conclusion has never been confirmed, however, and as there were no accompanying archeological specimens it cannot be said that the skeleton was that of Folsom man. It is unquestionably Indian, and certain characteristics of the skull—its definite long-headedness, heavy brow ridges, and deeply depressed nasal root—are rather primitive (Roberts, 1937), but the bones themselves give no hint of the time when the individual lived. On the basis of the physical features he could be late Pleistocene or early Recent or, on the other hand, a modern Indian. Unfortunately, the geologic evidence needed to reach a verdict is not available.

One fragmentary skeleton was recovered from the oldest level of the Cochise. The bones were so broken and so many pieces were missing that it was difficult to make a determination of the physical type. After careful study, however, it was concluded that the individual was one of the small, southwestern longheads belonging to the Basket Maker group. The Basket Makers were the first agricultural pottery-making peoples in the Pueblo area, in the period from the beginning of the Christian Era to about A. D. 600, and although they had some primitive features, they were essentially modern Indians. They are believed to have been in the region long enough to have made the transition from a simple nomadic-hunting economy to that of the hunting, food-gathering, and subsequent agricultural pottery-making stages that are well known from excavations in the Pueblo region. The Cochise occurrence may be considered substantiation for their relatively early appearance in the Southwest, although it might be regarded as an indication that the Cochise is not as old as has been suggested.

In the Abilene district, burials are found at varying depths in the silts containing implements of the Clear Fork Complex. Some were unquestionably subsequent penetrations into the silts, but others seem to date from the period when they were forming. The best

example of the latter was brought to light when high water in the Clear Fork of the Brazos River caved off a section of bank some 60 miles northeast of Abilene and exposed a grave 21 feet below the present valley floor (Ray, 1943). Portions of the skull and all the hand bones were swept away by the flood. Enough remained, though, to give a good indication of the type of individual buried there. The profile of the deposits showed an unbroken series of strata extending across the top of the grave and rising from what had been the level of occupation at the time when it was dug to the present surface. There is no question that the burial was made in the early stages of the deposition of the silts and that it was as old as the lowest of the overlying strata. As these are in the portion of the silts identified as probably being late Pleistocene in origin, the skeleton would be of similar age. The tip end from a small stone blade was found in the grave but, unfortunately, it is not sufficiently characteristic to indicate its cultural affinities. The bones show that the individual was a tallish, moderately robust male about 40 years of age. He had exceptionally heavy brow ridges, a long head, and a broad, rugged lower jaw. The skull in some respects might be approximated by occasional recent Indians, although in the main it agrees more frequently with the more primitive forms of morphologically modern-type man found in America. Since from its general features the skeleton could be that of a Paleo-Indian, there is nothing anachronistic in its being found in deposits that are late Pleistocene or early Recent in age. Other remains from deep burials in the Abilene region have shown similar characteristics and have been considered as exemplifying a very primitive American Indian, probably one of the earlier strata of the American population (Hooton, 1933).

One of the few examples of a burial attributable to a fairly old horizon and accompanied by artifacts was that of the Browns Valley man in Traverse County, Minn. (Jenks, 1937). It was found in a gravel pit while material was being removed for use in highway construction work. The bones were in a grave that had been dug in late glacial or Pleistocene gravels subsequent to their deposition but prior to the formation of a thick humus layer that rested on them. Conclusions based on geologic studies of the site are that the interment was made in early postglacial times, that is, in the beginning of the Recent period. The associated implements consisted of three points and two knife blades. In the original description they are classified as Yuma-Folsom because of certain features that are suggestive of each. In view of later information about those types, as previously mentioned, it seems that Browns Valley artifacts would be a better designation. They are good examples of one of the older patterns in cultural material and merit a distinct name. The skeleton was that

of an adult male and, as in the cases already discussed, the skull was of the long-headed variety with strong development of the brow ridges, and a broad, heavy jaw. The individual was undoubtedly an American Indian, but he differed from the recent Indians known to have occupied that particular region.

Another Minnesota skeleton, the remains of a girl about 15 years of age, has been proposed as an example of the physical type of the Paleo-Indian living in west-central Minnesota in late Pleistocene times (Jenks, 1936). The matter of its antiquity has been questioned in some quarters, however, and there has been considerable controversy over its proper status. The remains were discovered by workmen repairing a stretch of highway in Otter Tail County when the grader blade, making its deepest cut in the middle of the roadbed, exposed fragments of a broken clam shell. Stopping to investigate, the workmen found the frontal of a human skull beneath the bits of shell and a short distance away a piece of what they thought to be bone but which later proved to be the greater part of an implement made from antler. The road boss interrupted work with the heavy equipment until the find could be uncovered and within the space of 2 hours most of the skeleton had been removed. At the start several of the bones were damaged by the shovels being used in the digging. When they were discarded for small hand tools the results were better and most of the material was recovered in fairly good condition. The skull had been crushed by the weight of the grader wheel but had not actually been touched by it, nor had the grader blade come in contact with any of the other bones. A shell pendant found among the ribs and vertebrae probably had been worn suspended from the neck.

During the progress of the disinterment a number of the men not participating in it watched the process, studying and discussing the nature of the surrounding earth. From their statements, and from the profiles made by the highway engineer prior to the original construction, it was concluded that there had been no break in the overlying strata, and that the body had not been buried intentionally but had been covered by the deposition of silts around it after it had come to rest at that particular spot. The repairs on the highway were completed, and the bones were turned over to the University of Minnesota. After they had been studied it was evident that they exhibited a number of primitive characteristics and further examination of the place where they were found was deemed advisable. On two different occasions traffic was diverted and the site reopened. These investigations demonstrated beyond question that the skeleton had come from that location. Fragments of bone were obtained that fit pieces recovered in the initial digging, and in addition animal and bird bones and many segments of turtle carapace were found. While

the pit was open, geologists studied the deposits and came to the conclusion that they were varved clays of a glacial lake, subsequently named Lake Pelican. There is no question about the identification of the silts, but there has been contention over the nature of the burial. Many think it was contemporaneous with the clays, and the testimony of the workmen and the highway engineer is good basis for such belief, while others hold that it must have been a later penetration. Furthermore, there has been contention as to whether it was intentional or accidental, whether the body had been placed in a grave or, as has been suggested, the girl fell from a boat or through a hole in the ice, drowned and sank to the bottom where she was covered with gradually settling sediment. The problem is complicated even more by arguments over possible evidence for slipping and disturbance in the clays and the chance that the skeleton may have been intrusive. Unfortunately, the issue can never be settled to the satisfaction of all because of the manner of its discovery and its location beneath a highway.

The artifacts are of little help because similar antler and shell objects might be found accompanying any burial in that region, even those dating as recently as early historic times. The fragments of bone from muskrat, wolf, loon, and turtle carapace also present in the pit are from species that could be Pleistocene but also are modern and indicate climatic conditions little different from those of today, hence cannot be stressed as evidence. Because of all these factors opinion is about equally divided; some consider the age as late Pleistocene and others as clearly Recent. Careful review of all phases of the problem, however, would seem to indicate that the probability of a late Pleistocene dating outweighs that of a Recent age. The skeleton has a number of primitive features, the most outstanding being in the skull. The forehead is low and sloping, with prominent glabella. There is a backward extension of the cranial vault to a large occiput with a large projection to the rear and evidence for a high area of attachment for the neck muscles. The nose is relatively small and narrow, lacks a nasal sill, and has a poorly developed nasal spine. There are deep subnasal gutters, and there is marked alveolar prognathism. Obvious lack of reduction is apparent in the jaws and teeth, a feature usually considered definitely primitive. The lower molars in absolute size are larger than any of those in the lower jaws of 10 late Pleistocene men in Europe, and this in conjunction with other less developed characteristics is regarded as good evidence for the remains being those of an early type of modern man. There is no reason from the standpoint of their osteology why they could not be as old as the silts indicate. On the other hand they do fall within the range of variation in the modern Sioux and are believed

by some of the physical anthropologists to belong in that category. In this connection it may be mentioned that this is the only example among the many purported early American skeletons where the skull is not definitely of the long-headed type. In this case it is mesocephalic.

THE MEXICAN AREA

There has been little evidence thus far for Paleo-Indians in the Mexican area. No Folsom-type points, with the exception of the two in Sonora about which practically nothing is known and one possible fluted blade from Tamaulipas (Prieto, 1912, fig. 13), have been found south of the Rio Grande. Some discoveries suggestive of certain antiquity have been made, yet none has been demonstrated to compare in age with Sandia, Folsom, and similar complexes. In fact it is agreed that they are much more recent (Martínez del Río, 1943, pp. 168-170). It seems improbable, however, that no such finds will be made; there is always a chance that one will come to light. Up to the present so little work has been done in the northern districts that, with the exception of knowledge of the occurrence of some scattered late village sites and protohistoric ruins and a few caves that date within the Christian Era, there is virtually no information on the remains in that area. Bison roamed as far south as southern Durango and were in the region around Monterrey in Coahuila as late as the beginning of the seventeenth century (Hornaday, 1889, p. 382), and there is the possibility that older species may have occupied the area as well because there are several large deposits of bones weathering from the beaches around the beds of lakes that must have dried up several millennia before the coming of the Spaniards. Hasty examination of these bone beds indicated that much of the material was bison, but no attempts were made to collect specimens or to determine the species. It is not improbable that some of the older forms are represented there, and inasmuch as the earlier peoples were mainly hunters and followed the game in its migrations, it would not be surprising if, eventually, bones from extinct bison accompanied by types of implements made by the Paleo-Indians were found there. If the generally accepted ideas about the peopling of the New World from Asia are correct, the Mexican plateau must have served as a broad highway to Central and South America, and although it may be difficult to find, there should be some evidence of the migrations passing that way.

CENTRAL AMERICAN FINDS

Finds in Central America show that the bison formerly ranged much farther south than Mexico. A horn identified as bison came from northern Nicaragua many years ago (Rhoads, 1898), and tracks

made by bison were recently reported from west-central Nicaragua. The latter are of more than passing interest because of their association with imprints left by barefooted human beings (pl. 10, fig. 1) as well as with those of other animals and birds. They were uncovered by quarrying operations in a deeply buried volcanic stratum at El Cauce, in the outskirts of Managua (Richardson, 1941; Richardson and Ruppert, 1942). Studies of the deposits have led to the conclusion that the track-bearing layer was produced by a flow of semi-liquid mud from a vent on higher ground. While the surface was still sufficiently soft to receive perfect impressions the people and animals passed over it. Shortly thereafter a thin fall of dry cinders covered the tracks, preserving and protecting them so that today they are as sharp and clear as when first made. Subsequently there was another mud flow and eruption of black cinders and then a rapid succession of thick mud flows (pl. 10, fig. 2). In the course of time these layers turned to stone, a phenomenon comparable to that occurring at Herculaneum after its destruction by Vesuvius in A. D. 79. A stream forming a channel some 65 feet wide and 10 feet deep then cut its way through the strata thus formed. Eventually the bed of the stream filled with silt, gravel, and water-rolled stones. Later the area was covered by a heavy fall of pumice from the eruption of a distant volcano, and during the following quiescent interval new stream channels were cut and a thick soil zone developed. Again more ashes fell and another soil zone accumulated to be covered in turn by pumice from a further eruption. Finally the present topsoil developed to a depth of from 4 to 5 feet. The lowest portion of this layer is an aeolian deposit representing a period of slow growth (Williams, in Richardson, 1941). The sequence of events recorded in this series of strata required considerable time for its consummation, and although conclusions as to the age of the footprints await the completion of volcanological studies now under way, it appears certain that appreciable antiquity is indicated.³

Journals of the conquest period presumably contain no references to bison for this area, and everything indicates that they have long been extinct in Nicaragua. Since their tracks and those made by men are unquestionably contemporaneous, the occurrence would tend to signify that the human occupation should be regarded as dating from fairly early times. Lending strength to this assumption is the fact that between the footprints and overlying archeological remains are approximately 10 feet of deposits. Included in the material from the lowest cultural level of the later manifestations are potsherds from

³ The work of F. B. Richardson, of the Division of Historical Research of the Carnegie Institution of Washington, and that of Prof. Howell Williams, of the University of California, who was cooperating in the investigations, was interrupted by the war but will be resumed as soon as hostilities have ceased.

a type of ware found only in the earliest ceramic horizon in Guatemala and El Salvador. This argues for a relatively ancient population in the Managua district. As the footprints occur at a much greater depth and must be considerably earlier, it is possible that they constitute the oldest trace of human presence thus far noted in Middle America and that they will establish the period of migration at a date some millennia prior to that hitherto postulated.

SOUTH AMERICA

The situation in South America is somewhat different. Numerous discoveries have been proposed as evidence for an early occupation, but there is much disagreement over their actual import. Several factors contribute to conflicting opinions about the problem. In many portions of the continent there is difficulty in identifying and correlating deposits. Certain animal forms appear to have survived longer than in the north, with a corresponding lessening of the significance of faunal associations. Other complications have resulted from a rather common tendency to place undue reliance on the typology of implements, picking and choosing those that suggest antiquity while failing to consider the remaining components in a complex. Furthermore there has frequently been complete disregard of the situs of the finds, resulting in anachronic and wholly misleading conclusions.

At the time of its discovery the Punin calvarium from Ecuador aroused considerable interest, and it is often mentioned as an example of "early" man from that area. Only the skull was found. It came from a deposit of volcanic ash in which also were bones from the extinct Andean horse, a large ground sloth, a so-called camel (the *Protauchenia*), the Andean mastodon (*Cordillerion*, a "Bunomastodont" not to be confused with the North American mastodonts), and those from present-day animals (Sullivan and Hellman, 1925). There was not an actual association, the nearest animal bones being 50 to 100 feet from the skull. The discoverer, however, expressed the opinion that serious consideration should be given to the implied contemporaneity. The skull falls into the category of one of the three types generally believed to be characteristic of the oldest stratum of New World peoples. This particular form has been designated Australoid (Sullivan and Hellman, 1925), Pseudo-Australoid (Hooton, 1930), Proto-Australoid (Dixon, 1923), and Fuégido (Imbelloni, 1937). The questions of nomenclature, identifications, somatological inferences, and true significance of the type are too varied and complex for consideration in this presentation. The Punin calvarium is admittedly an archaic Indian form and could be relatively ancient but, as in the case of the North American skeletal material, the age must be based on geologic-paleontologic evidence and not on the nature of the skull

itself. The ash deposit has not been correlated with any specific geologic horizon. The faunal assemblage occurring in it is generally considered as Pleistocene, and were it not for the human remains, the layer no doubt would have been regarded as of that age. Yet other evidence, such as that of the "Bunomastodon" (*Cuvieronius*) found near Alangasi, Ecuador (Uhle, 1930), suggests that the animals continued well into the Recent period before becoming extinct. The fact that the quantity and variety of animal life in the Punin district has been much poorer in modern times than it was in the period when the volcanic ash was being laid down indicates some antiquity, yet the evidence for early occupation is not as convincing as is desired.

The Confins man from the highlands of the state of Minas Geraes, Brazil, was a more satisfactory discovery (Walter, Cathoud, and Mattos, 1937). This skeleton was found in 1935 in a cave in the Lagôa Santa region where the Danish naturalist Lund made his extensive and well-known collections over a century ago. The entrance to the cave was uncovered during the course of excavations in an Indian shelter and burial ground dating from about the conquest period. As the blocks of fallen stone and conglomerate were removed in the search for graves, the entrance was gradually exposed and ultimately stood entirely clear so that the cave was accessible. There were no traces of human occupation in the upper alluvial deposit of the floor, and, as careful investigation showed that the entrance had been sealed during pluvial times, it was quite evident that the existence of the cave was not known to the people who used the shelter and buried their dead at its mouth. It was not until the fourth year of exploration in the interior of the cave that the human remains were found. The bones lay beneath approximately 7 feet of alluvial silts that had been sealed in by a layer of stalagmite. Natural rather than intentional burial was suggested by the position of the remains. The body evidently had rested on the surface and gradually was covered by sediments carried in by successive floodings from a nearby lake. In the same stratum were bones from the giant sloth, large llama, an extinct horse, tapir, bear, giant capybara, peccary, and mastodon. This assemblage constitutes what is usually regarded as a typical Pleistocene or pluvial age fauna in that area. No artifacts accompanied the skeleton and none were found in the deposits in the cave, hence there was no indication of cultural affinities. The skull is of the long-headed variety with low forehead and, although comparable to the Lagôa Santa type in its hypsicephaly, presumably does not belong in that category. Students who have examined it consider it one of the most primitive forms of Paleo-Indian thus far found in South America.

Contemporaneity between the human and animal remains is indisputable and appreciable antiquity is indicated both by the depth of

the overlying silts and the thickness of their stalagmitic cover. The high-water level in Lake Confins, from which the silt-bearing floodwaters are believed to have come, at present is 65 feet below the bottom of the cave. Throughout historic times there has not been sufficient water to produce overflowing into the cave, and consensus is that only near the end of the Pleistocene or corresponding pluvial period was there adequate precipitation to cause such phenomena as the deposition of the silts and the formation of the stalagmite. At present knowledge of that period is too incomplete to provide a basis for chronological estimates on the age when the pluvial came to an end in the area. Some of the animals represented in the faunal assemblage seem to have survived into relatively recent times and consequently are not much help as a criterion. The Confins man was unquestionably "early" insofar as his relationship with subsequent inhabitants of the region is concerned, but just how ancient he actually was is a problem still waiting to be solved.

The *Sambaquis*, shell heaps scattered along large sections of the coast of Brazil and on the banks of certain rivers in the interior, should be mentioned, although their value as evidence for an early occupation is debatable. There is considerable variation in the size of these formations. Some of them measure 300 to 350 feet in length and 50 to 80 feet in depth. In most cases, however, they are not as extensive and not more than 10 to 20 feet deep. Many are located some distance from the present shore line. This indicates that they were formed when the sea was at a higher level, and for that reason they are regarded as being of considerable age. They have been referred to as evidence for a fairly early and dense population in the area because many people have believed that all were of human origin despite suggestions from time to time to the effect that most of the large ones probably were the product of natural forces. Recent investigations tend to substantiate the latter point of view (Serrano, 1938). None of the shells in the larger heaps have been opened, and such traces of human activity as have been discovered apparently were intrusions and not contemporaneous material. Various small heaps and occasional portions of some of the medium-sized ones, however, consist of kitchen-midden deposits or refuse and definitely are man-made. The small heaps located furthest from the sea in the southern provinces, especially in the São Paulo district, yield the oldest-appearing artifacts. A simple culture in strong contrast with that of historic times is represented. Stone and bone implements comprise most of the complex. The stone tools are as a rule roughly chipped, but they are polished along the edges. Potsherds are sometimes found on the surface or in the upper part of the top layer of such mounds and the evidence suggests a late pre-ceramic group just beginning to acquire pottery. This, in combination

with the polished edges on the stone artifacts, points to a later horizon than that indicated for some of the complexes previously considered. Further investigations are desirable to establish more precisely, if possible, the exact status of these manifestations because finds farther south furnish a basis for the assumption that a relatively old culture may have existed in this region.

In Argentina there has been active interest in the subject of "early man" ever since the discovery of bones from extinct animals and stone implements in the Mar del Plata region and the announcement of a *Homo pampaenus* (Ameghino, 1909). This area is very productive archeologically. There are many sites where house remains, pottery, and metal objects are found, but in addition there is an older horizon which is characterized by a different human physical type and an implement complex containing only stone and bone tools. Furthermore there are sporadic occurrences of artifacts, presumably in association with extinct faunal material, and human skeletons that have been presented as evidence for varying degrees of antiquity. Arguments over their validity have flourished for many years, and they still furnish a fertile field for debate. It is not within the scope of the present paper, however, to review and discuss all these finds. Efforts to demonstrate that the cradle of the human race was in South America stirred a controversy that produced a voluminous literature. Information on the subject may be found in the numerous publications detailing both sides of the question. Consensus is that in the beginning entirely too great an antiquity was proposed for these remains, but that some of the theories advanced in explaining them may have some justification when adapted to a more conservative time scale.

Geologic evidence in Argentina, as elsewhere in South America and in many portions of North America, tends to be confusing and to promote errors in correlation and cross dating. Finds frequently are made in dune districts where artifacts are uncovered by wind action and are left exposed in the bottoms of large depressions or playas (Greslebin, 1930). The situation is comparable to that in the so-called blow-outs of the western plains in the United States. The relationship between objects lying on the top of a hard substratum is always problematical because they may have been at different levels before they were dropped to a common surface when the surrounding earth was blown away. Also, some of the specimens may have weathered from the top of the lower layer, as often happens in the case of animal bones, and there may seemingly be an association between artifacts and an extinct fauna when the man-made objects actually belong in a later horizon. For that reason such occurrences are properly open to doubt. That the degree of minerali-

zation in human and animal bones is not a reliable criterion for antiquity apparently has been overlooked or disregarded by some of the advocates for an early occupation of this area. Reliance on the typology of implements also is misleading because, as has been demonstrated elsewhere, some tool forms persisted over long periods, and similarities between Old and New World specimens do not constitute proof of their contemporaneity. Artifacts may be paleolithic in type but not in age, a factor that has been forgotten by many arguing considerable age for certain specimens in this locale. However, some discoveries indicate that occupation of this area was not wholly a recent event. This is particularly true of a number made in late years, which suggest that while the antiquity is not as great as earlier claims would make it, the age probably compares favorably with that generally recognized for North America. Because of finds made in southern Patagonia, evidence from future investigations in Argentina will be studied with considerable interest.

A definite association between human remains, an extinct fauna, and an interesting series of artifacts has been reported from southern Patagonia, in Chile just south of the Argentine border (Bird, 1938). The evidence was found in caves and a rock shelter. One of the caves, named Palli Aike, was located in an old volcanic crater and contained deposits which in places attained a depth of 8 feet 6 inches. The upper 5 feet of the deposits was composed of fine, dry dust with an admixture of broken and burned bones and some stones. This stratum rested on a layer of volcanic ash that had a maximum thickness of 2 feet. Throughout the ash and scattered over the original rock floor were large blocks of lava that had been erupted into the cave at the same time as the ash. The upper 18 inches of the deposits contained stemmed arrow points, knives, various kinds of scrapers, and bolas. Among the points from the top 6 inches were finely made specimens of the type attributed to modern Ona Indians. Larger and cruder stemmed forms occurred throughout this 18-inch level. Stemless points and other kinds of implements came from the next layer, 18 inches to 3 feet below the top. Various types of scrapers and other stone and bone implements, but no points of stone (the few found were made of bone), came from the stratum between 3 feet and 5 feet. On the surface of the underlying layer of volcanic ash were tools of stone and bone, debris of occupation, fireplaces, and broken and burned bones from the ground sloth and native horse. Embedded in the top of the ash was the stem from a different type of stone point. Toward the back of the cave three cremation burials were found along the base of the wall in hollows in the top of the ash. This provided important evidence of contemporaneity between human remains, extinct animal bones, and artifacts in what probably is the first well-authenti-

cated occurrence of the kind in the New World. The ash layer contained several partial sloth skeletons, and it was obvious that the animals had used the cave as a shelter and had died there. Nothing suggested that they had been killed by Indians, but that the latter had been there during the early period was shown by the charcoal and stone flakes present in the debris on the original floor.

Some 20 miles west of Palli Aike, in the valley of the Río Chico, was a formation called Fell's Cave, although strictly speaking it was a shelter rather than a true cave (pl. 11). It had been formed at some time when the river undercut the canyon wall. The deposits there were slightly over 8 feet in depth and contained another interesting sequence. The top layer consisted for the most part of sheep dung and produced no artifacts. The stratum below it, however, yielded evidence of four cultural horizons. There was no structural change in the geologic debris, and clearly marked lines of demarcation were absent, but the archeological and faunal material was sufficiently differentiated to demonstrate the levels. In the latest horizon were Ona-type points and some of the larger, cruder, stemmed forms like those present in Palli Aike. The next level contained only the latter kind of points, while below it were stemless points and blades. Scrapers of various kinds occurred throughout the stratum, but it was only in levels containing stone points that bolas were found. Associated with this material were bones from the guanaco, fox, and bird. There was a marked change in the proportions from the top downward until at the bottom, which was the bone-point horizon, bird and fox bones predominated and those from the guanaco were only sporadic.

Underlying the above stratum was a sterile layer, 15 to 28 inches thick, composed mainly of slabs, blocks, and disintegrated pieces of conglomerate that had fallen from the ceiling. This debris completely sealed off from the upper levels a layer of occupation refuse ranging from 3 to 9 inches in depth. Numerous artifacts, stone flakes, and bone fragments were scattered through it, and there were four hearths where fires had burned. Broken and burned bones from the giant sloth, native horse, and guanaco were mixed with the charcoal and ashes. Artifacts in the layer were bone implements, various kinds of scrapers, cylindrical rubbing stones, chopping stones, and 14 roughly made stemmed points of stone. These specimens show that the first occupants of the shelter had an entirely different material culture from those who used it later. The stem from a point found in the top of the ash layer in the bottom of Palli Aike Cave is from the same type as all but one of the points from the bottom stratum in the shelter and serves, with those from upper levels, to demonstrate that the same type sequence prevailed in both locations (pl. 12). The

single differing point from the bottom level of the shelter in its outline suggests a Folsom point, but actually it was not of that type. During the interval between occupations, that characterized by the rock fall, the horse and giant sloth disappeared and the guanaco became rare. The latter as a matter of fact did not return in sufficient numbers to become an important food item until the closing days of the stemless-point period or third cultural horizon.

At no great distance from the shelter and in the side of a hill called Cerro Sota is a long, narrow cave. The upward-sloping floor was covered at the inner end with a deposit of fine, dry dust 5 feet deep. In the lower 3 feet of this debris were many fragments of native horse bones and a few from those of the sloth. There were no artifacts, and the only signs of fire were those associated with the cremation burial of a group of 3 adults, 2 children, and 2 infants. The bodies had been placed in a hollow at the rear of the cave, had been surrounded with grass and then burned. There were no accompanying artifacts to indicate the cultural affinities of the remains, but it seems likely they belonged to the first or oldest horizon. The fact that the earth above the burial contained broken horse bones suggests such a correlation. The skeletal material both from this cave and Palli Aike shows that the people were long-headed, had general Indian characteristics, and in some traits resembled those whose remains were found in the Lagôa Santa Cave.

Unquestionable association with an extinct fauna indicates certain antiquity for these finds, but again the question of when the animals disappeared is all important and there still is no satisfactory answer. This part of Patagonia was on the edge of the extension of the Pleistocene ice sheet in that area, and a possible correlation between the retreat of its last advance and other phenomena suggest that people may have been in the region to the east prior to the recession. At the time the excavations were made, a relative chronology was developed on the basis of a correlation between evidence for marked land rises, a change in the level of the Río Chico, the subsidence of Laguna Blanca located some 60 miles west of Palli Aike, and clear indications that the volcanic eruption recorded in the bottom level of that cave was the oldest in the sequence. The initial occupation of Fell's Cave apparently preceded the eruption, and the third period seems to have ended with the drop in the level of Laguna Blanca. Independent studies have suggested that the subsidence in the lake was synchronous with the last ice retreat, and if this were the case it would tend to establish appreciably early inhabitation in the area. The native horse and the giant sloth seem to have disappeared soon after the volcanic disturbance, when there may have been a rather severe but relatively brief fluctuation in climate. These factors give no real

date, of course, but they do furnish a basis for making estimates. This will be considered in more detail in connection with the discussion of the ages which have been assigned to all such finds.

SUMMARY AND DISCUSSION

It is evident, from the manifestations discussed in preceding pages, that man had reached the New World when large portions of North America were still covered by remnants of the Wisconsin ice sheet. The physical characteristics of such remains as have been found, as well as those of the later Indians, indicate an Asiatic origin and subsequent migration. This spread probably did not take place as a single mass movement but as a series of continuing migrations by relatively small bodies of people over a long period of time. When this began and the routes followed are matters about which opinions differ. Most students of the problem, however, agree that the bulk of the aboriginal population arrived by way of the Bering Strait region and from there gradually spread over North America, through Middle America, and into the southern continent. The great central plain in Alaska and the lowlands bordering Bering Sea and the Arctic Coast were not glaciated during the last stage of the Pleistocene. Moreover, there was an open corridor along the eastern slopes of the Rocky Mountains in the period just after the climax of the Wisconsin. As a consequence it was possible for men and animals to pass from central Asia to the tip of Siberia and across to Alaska, eastward to the Mackenzie River and thence southward into the northern plains. Another route by way of the upper Yukon and its tributaries, the Liard and Peace River valleys, opened subsequently, and not long after this still another became available. It led south along the Fraser River, between the Rockies and the Coast Range, and into the Great Basin. The presence of artifacts, old camp sites, and bones from extinct species of animals found in various places demonstrates that full advantage was taken of these several natural highways.

The first migrants were hunters and they undoubtedly traveled in small groups. According to present evidence they followed two main lines of dispersal, one along the eastern slopes of the Rockies, some continuing on south toward northeastern Mexico, and others spreading out over the plains to the more southerly reaches of the Mississippi River and from there to eastern portions of the country. It may be pure coincidence, but it is interesting to note in passing that the northern boundary of the distribution of sites attributable to these people approximates the line of moraines left by the retreating glaciers following the climax of the last Wisconsin substage. The other movement seems to have been along the plateau between the Rockies and the Coast Range into the Great Basin, southern California,

Arizona, and probably from there into northwestern Mexico. The latter movement may have continued along the strip of coast west of the Sierra Madre Occidental, while the groups from the eastern division who proceeded southward presumably traversed the plateau between the Sierra Madre Oriental and the Sierra Madre Occidental. Eventually descendants from both must have passed through the Middle American funnel and into South America, where some possibly spread along the Venezuelan Andes and into the plains of the Orinoco and others continued southward along the Andes to southern Bolivia, where they scattered southeastward across the Gran Chaco into Brazil, south of the Amazonian Forest, and on south into Argentina. Some may have crossed the range to the west and emerged in the coastal belt south of the Atacama Desert (Sauer, 1944, pp. 558-559). The major movements that provided most of the Indian populations, however, appear not to have developed until later when the Recent period was well established. Such accretions as may have come by sea were too late to affect the older groups and too small to play much part in the later developments.

Although in many cases they apparently outlived the geologic Pleistocene, many of the animals killed by the early peoples constitute what are usually considered Pleistocene forms. They seem to have survived through the transition to Recent times and then to have become extinct rather suddenly. Causes of this widespread and rapid disappearance are not known. That the Paleo-Indians may have been a contributing factor through slaughter of the animals and the introduction of diseases to which they were particularly susceptible has been suggested. Other phenomena, no doubt, were also involved, and future work may produce the information necessary to a solution of this interesting phase of the problem. In this group of mammals in North America were: mastodons, mammoths, ground sloths, horses, camels, and tapirs, from families now extinct; antilocaprid, the giant beaver, the short-faced bear, saber-tooth cat, giant cat, musk ox, and bison, from genera and species now extinct but from families still persisting. In South America those from extinct families were: ground sloths, glyptodonts, "Bunomastodonts," horses from the short-legged type derived from the late Pliocene immigrant, and the Pleistocene *Equus*; while extinct genera and species from persisting families are represented by an armadillo, the short-faced bear, and saber-tooth cat (Colbert, 1942). The early inhabitants of both North and South America probably were contemporaneous with other animal forms, but their remains either have not been found in direct association or the association was too doubtful to receive consideration. Since many of these animals seem to have become extinct at a relatively recent date, associations between their bones and artifacts do

not necessarily indicate any great degree of antiquity. When such occurrences are in deposits that can be correlated with geologic phenomena attributable to the late Pleistocene, however, dating the assemblage as of that time is justifiable. Some of the North American evidence indicates that the earlier migrants were in the New World at the end of that period and on the basis of certain interpretations of the Patagonian manifestations it would appear that some must have arrived well before its termination.

To describe in detail the different implements comprising the various complexes and those occurring in sporadic assemblages of bones and artifacts has not been possible in the bounds of the present discussion. It may be said that there are examples suggestive of late Paleolithic tools, a few Mesolithic forms, and numerous early Neolithic types. Comparisons are frequently made between these implements and those from various European stone industries. This is misleading, however, as the American examples must have been derived from eastern Asia where the development of stone working was for the most part independent of that in Europe. Such similarities to European types as may occur have no chronological significance and should not be used as criteria for dating New World material.

There has been considerable disagreement and much argument over the date of the arrival of the first immigrants from Asia. This situation may be attributed to the basing of conclusions on such differing factors as the characteristics of the archeological material, the faunal assemblages, the nature of the human skeletal remains, and the geologic evidence. The latter as a rule is considered as being the most acceptable, and dates based on it are now regarded by many as substantially correct. Without going into the problems of glacial variations and synchronization, varve counts, fossil pollens, and related subjects, it will suffice to say that from these sources the ages of various phenomena have been determined. The opening of the corridor east of the Rockies, making migration southward from Alaska possible, has been placed at 15,000 to 20,000 years ago. There appears to have been a similar opening some 20,000 years earlier, but it is generally considered as being too ancient to have played a part in human activities. The termination of the last pluvial in the North American Southwest, which is important in the study of a number of the manifestations, has been dated at approximately 10,000 years ago. The Lindenmeier site in northern Colorado is dated at from 10,000 to 25,000 with the statement that it may have been nearer the 25,000 mark (Bryan and Ray, 1940), although other authorities consider the 10,000 figure as more nearly correct (Sayles and Antevs, 1941, p. 41, note 29). The Black Water Draw, between Clovis and Portales, N. Mex., has been dated 12,000 to 13,000 (Antevs, 1935a). The oldest level of the Cochise is

put at a little over 10,000 (Sayles and Anters, 1941). Gypsum Cave in Nevada is given as 8,500 (Harrington, 1933). Ventana Cave has not been dated as yet, but on the basis of similarities with other remains it is probable that the oldest level there would approximate the 10,000 figure. Sandia Cave seems to fall into the same category as the Lindenmeier or Black Water Draw.

No date has been suggested thus far for the human footprints and bison tracks in Nicaragua. The Confins man was considered as having lived a "few thousands of years ago" (Walter, Cathoud, and Mattos, 1937), and the remains in Patagonia have been estimated at 3,000 to 5,400 (Bird, 1938b). An interesting question has developed in regard to the latter, however, since that estimate was made. If the subsidence of Laguna Blanca took place at the time of the retreat of the last ice sheet in that area, the cultural horizons antedating that occurrence would be much older. On the basis of a correlation between the varves in the Northern and Southern Hemispheres the time of the recession in the lake has been placed at about 10,000 years ago. Inasmuch as the deposits at Palli Aike Cave have suggested that the entire period of human occupation of the area may be twice as long as the interval since the retreat of the ice, plus a span of unknown duration when the debris was collecting on the original floor and the layer of volcanic ash was accumulating, something over 20,000 years would be indicated.⁴ In view of the situation in North America this appears to be too long a period, but it raises the question as to whether the remains may not be older than originally postulated. The problem is directly involved in that of the synchronization of ice ages in the north of the Northern Hemisphere with those in other parts of the world, and as there are various indications that simultaneous ice ages for the whole earth are not necessarily admissible it is possible the Patagonian phenomena were actually somewhat later. There is no way of telling at this stage of the investigations how long it took the migrants to travel from northern North America to the tip of South America. Some think of it as a slow and laborious process, others believe that it may have been relatively rapid. If 15,000 be taken as the maximum for North America and 10,000 for the southern end of South America, the Nicaraguan manifestations might be considered as approximating 12,000 to 13,000—providing, of course, they represent the earliest north-to-south drift—and Punin and Confins between 11,000 and 12,000. The North American data apparently have a better foundation than those from South America, and there is a possibility that the dates just postu-

⁴ Information received from Dr. Bird in a letter written after the appearance of the original article in *Acta Americana*. On the basis of present evidence Dr. Bird believes such an age far too great.

lated for the latter are too great, although the former estimate for Patagonia may be somewhat too conservative.

There is nothing in the human physical types that would conflict with a 10,000- to 15,000-year age for the first occupation of the New World. In Upper Paleolithic times throughout the Near East and Europe, as well as in eastern Asia, several races of modern-type man were in existence at an earlier stage than any thus far suggested for the New World. Consequently the fact that the earliest arrivals did not differ greatly from modern Indians and have shown only sporadic primitive features should not be regarded as denying the possibility for such an age. However, the situation is somewhat different archeologically. Thus far there is scant information about the late Paleolithic in eastern Asia beyond the fact that there was such a stage and that certain types of implements correlate with it. There is little that compares with these older forms in the New World material, but there is much that is like the Neolithic artifacts of the period just preceding the appearance of pottery and various polished-stone tools. Because of this some argue, with considerable logic (Spinden, 1937), that the New World complexes could not possibly have originated prior to 5,000 to 6,000 years ago, while others are willing to concede a maximum of 8,000. The answer probably is to be found in Asia in the transition stage between the end of the Paleolithic and the appearance of the full Neolithic. At present there is no available information on that cultural phase, and until the results of future investigations are at hand there can be no decision in the matter. This seeming discrepancy between geologic dates and archeological evidence emphasizes the need for further study of the problem.

Thus far there is not much basis for correlations between the older types of remains with those of later Indian groups. With the exception of the Cochise, and possibly also of some of the manifestations in the Abilene district, all the early complexes were followed by a definite break. They are separated from subsequent assemblages by a sterile layer. The later manifestations, however, in all cases appear to continue through a series of cultural horizons down to historic times. The break in continuity is unmistakable in the Folsom sites, Gypsum Cave, Sandia Cave, Ventana Cave, and numerous other North American occurrences not described in the present article, and also at Fell's Cave in South America. In view of this and because of the relationship between some of the Ventana Cave and Cochise materials, as well as the difference between the oldest Cochise and other early complexes, it is possible that the bottom level of the Cochise may have been placed one stage too early and that it actually belongs in the phase beginning just after the interval which is characterized, in all other locations where such remains are found, by an absence of traces of

human occupation. In fact some geologists think that the sand-gravel layer in which the Cochise material occurs may be a redeposition rather than an original flood plain and that the archeological specimens are later than the animal bones and gravel would indicate. If the widespread evidence for such a hiatus is correct, some explanation should be found for the break in continuity and for the possibility that the earliest migrants, like the animals they hunted, became extinct. On the other hand, if the first occupation was followed by uninterrupted inhabitation, some good reason for the sterile stratum in so many sites should be forthcoming. One postulation has been that the break merely was in the plains and the southwestern area, where the increasing temperatures and progressive desiccation following the onset of the postglacial produced unfavorable conditions and forced the people on eastward and southward to other regions where they continued to live. Eventually, after an amelioration of the climate in their former habitat and an influx of new migrants who found it again suitable for occupation, their descendants came in contact with some of the later peoples and there was an intermingling that is chronicled in the sporadic appearance of older physical types in recent groups. This is a logical explanation, but thus far the preponderance of archeological evidence is against it.

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FOLSOM POINTS AND KNIVES.

Top specimen in central column, a channel-flake; right-hand column, fluted knives. (Actual size.)



GENERALIZED TYPE OF FLUTED POINTS.
(Actual size.)



1. ORIGINAL FOLSOM SITE.

Man standing on level at which bones and artifacts occurred.



2. POINT AND BISON RIBS IN SITU AT ORIGINAL SITE.

(Photograph courtesy Colorado Museum of Natural History.)



1. LINDENMEIER SITE IN NORTHERN COLORADO.

Cross indicates area of major excavations.



2. ONE OF THE EXCAVATION PITS AT THE LINDENMEIER SITE SHOWING DARK-SOIL ZONE BENEATH WHICH ARTIFACTS AND BONES WERE FOUND.



1. ONE TYPE OF YUMA POINT.
(Actual size.)



2. SANDIA POINTS.
a, type 1; b, type 2. (Approximately actual size.)



SANDIA CAVE.
Arrow indicates entrance.



1. GYPSUM CAVE.

Arrow indicates entrance. Excavation camp in right foreground. (Photograph courtesy Southwest Museum.)



2. GYPSUM CAVE POINTS.

Specimen at right is $2\frac{3}{4}$ inches long. (Photograph courtesy Southwest Museum.)



VENTANA CAVE.

Oldest material came from upper and deeper section behind the man with the wheelbarrow. (Photograph courtesy Arizona State Museum.)



1. TWO SIDES OF VENTANA CAVE POINT.
(Photograph courtesy Arizona State Museum.)



2. DEEPLY BURIED HEARTH AND OCCUPATION LEVEL NEAR ABILENE, TEX.



1. HUMAN FOOTPRINTS IN LAVA AT EL CAUCE, NICARAGUA.
(Photograph courtesy Division of Historical Research, Carnegie Institution of Washington.)



2. DEPOSITS OVERLYING FOOTPRINTS.
(Photograph courtesy Division of Historical Research, Carnegie Institution of Washington.)



FELL'S CAVE OR SHELTER, RÍO CHICO VALLEY, SOUTHERN CHILE.
(Photograph courtesy American Museum of Natural History.)



SEQUENCE OF POINT TYPES FROM PALLI AIKE AND FELL'S CAVES.

Earliest forms at bottom. Second from bottom is a bone point. Small points in top row are Opn. (Photograph courtesy American Museum of Natural History.)

EASTER ISLAND¹

By ALFRED MÉTRAUX

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[With 4 plates]

A treeless volcanic rock, scarcely 13 miles long and 7 miles wide, slowly being eaten away by the waves and lost in the great emptiness of the Pacific Ocean—2,000 miles off the coast of Chile and 1,500 miles from the nearest Polynesian archipelago—this is Easter Island, the most isolated spot ever inhabited by man. Today it supports a mere handful of natives, mostly half-castes, and many of them lepers. These 450 people, now under Chilean rule, are the only descendants of the men who created there one of the most original civilizations that have left a trace behind. Yet they have all but forgotten their past.

For two centuries, the name of the island has been almost synonymous with mystery. In the world of ethnologists it occupies a place much like that of isles of fancy in children's imaginations.

The sense of mystery which still surrounds this lonely rock was first aroused on Easter Sunday, 1722, when the Dutch Admiral Roggeveen, in command of three frigates cruising about the Pacific in search of the fabulous Davis Land, saw the dome-shaped peaks of its volcanoes jutting above the horizon. From the decks of their ships his sailors, as they drew nearer, could discern all along the cliffs of this unknown shore an army of gigantic statues, which completely overshadowed a small band of naked and noisy savages on the beach below. The visit of the Dutch discoverers did not last long, but they carried back to Europe the strange tale of a solitary, desolate island guarded by colossal stone images, far too heavy and impressive to have been carved and erected by the few primitive people they found living there.

Later in the eighteenth century, and afterward, Easter Island was visited in succession by several other great navigators: Cook, La Pérouse, Kotzebue, Beechey. They, too, saw with amazement the stone monsters, measured them, and even sketched them. To their

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minds also, the contrast between the monuments, indicative of a flourishing and skillful population, and the desolation they found about them was a peculiar enigma. They spoke of cataclysms, of volcanic eruptions, that might have changed the course of the island's history, but these were pure guesses based on superficial observation.

In the first half of the nineteenth century, a different group of visitors appeared. These were the whalers, most of them enterprising New Englanders in pursuit of business and adventure in the South Seas. A few echoes of their experiences come to us in indirect ways. Thus we know that the captain of one of these ships kidnapped several men who afterward escaped and tried to swim back to their island although they were 3 days out. It is not surprising that relations between the whalers and the natives were far from cordial. Too often the ships' officers resorted to impressing the islanders into their service. Such incidents explain the hostility shown to some European navigators between 1820 and 1830 when they attempted to land. But these brief visits of Yankee sailors were not without benefit to the study of Easter Island. Thanks to their collecting instinct, numerous precious specimens of its early art have been well preserved in the Peabody Museum at Cambridge and the Peabody Museum at Salem. In Cambridge, besides various wood and stone carvings, there are two images brought from the island, made of bark stuffed with bulrushes, which represent a branch of its artistic tradition otherwise entirely unknown. They are covered with painted designs that reproduce, with fine and precise workmanship, the elaborate patterns used in tattooing up to a hundred years ago. In this respect the old Easter Islanders rivaled the achievements of the Marquesans.

In 1859 a frightful disaster befell the islanders when Peruvian blackbirders attacked the island and kidnapped the king, a large number of the nobles and priests, and many hundred commoners, all of whom were carried off to the guano islands of Peru to work as slaves. Most of the people died within a short time. When at last the few survivors were repatriated by a French ship, they spread among the remaining islanders the smallpox and tuberculosis contracted in Peru. Thus within a few years most of the native population and with them the vital links with the past were wantonly destroyed.

The mystery of Easter Island became still deeper when, in 1864, the first Christian missionaries (members of the French Order of the Sacred Heart) arrived and tried to obtain from the natives details about the origin of the statues, and the methods that had been used to transport them—since many of them had obviously been moved from the place where the stone was quarried. Their answers to questions of this kind were unilluminating and showed that they had only a vague tradition of what had happened before their time. Their ignorance, combined with the state of primitive poverty into which they

had fallen, again emphasized their enigmatic relation to the lost civilization, of which the statues and great stone mausoleums as well as other finely wrought remains of the past were mute evidence.

Then scientists began to study Easter Island. At what time and by what manner of men, they asked, were these images made, with their colossal bulk, their empty eyes and scornful expressions? Was the island the remnant of a sunken continent? Had it been inhabited by a powerful earlier race which had died out, or been destroyed and displaced by more warlike conquerors? Had eruptions of the volcanoes exterminated the skilled craftsmen, the sculptors, and the architects, leaving only a small group of people too discouraged and weak to continue the work of their forefathers? These are among the questions that still puzzle students.

The statues symbolize the mystery of the island and have made it famous. Yet their paradoxical presence on this speck of land in the midst of the Pacific is perhaps less difficult to understand than are the wooden tablets covered with small incised designs that were collected from the natives in the second half of the last century. The tablets raised the fascinating question whether their makers used on them a kind of hieroglyphic script which might some day be deciphered and would unveil the secret of its past. But all attempts to decipher them, with the help of intelligent natives, failed.

A few years ago the study of the tablets took an unexpected turn. A Hungarian linguist, Guillaume de Hevesy, published a long list of Easter Island hieroglyphs which, it was claimed, presented very striking analogies with the symbols of a newly discovered script found in the ruins of a civilization, 5,000 years old, in the Indus Valley at Mohenjo-daro and Harappa. There, coetaneous with the Sumerian civilization, flourished large and opulent cities inhabited by people whose name and affiliations are totally unknown to us. They were wiped out probably at the time of the Aryan, and their existence remained unsuspected until the great excavations of Sir John Marshall. The Mohenjo-daro people have left a great many inscriptions on seals which have so far resisted any attempt at decipherment. If it could be shown that the two scripts were related, new light might be thrown on the obscure past of the whole Pacific area.

The problem thus posed was of such significance for an understanding of the early history of man that the French Government in association with the Belgian Government decided to organize an expedition to Easter Island to try to read its riddle. The leader of the expedition was a French archeologist, Charles Watelin, who, unfortunately, died in Tierra del Fuego. I was then asked to carry on the research, in association with the Belgian archeologist, Dr. Henry Lavachery.

We saw Easter Island for the first time on a rainy day in winter. It was also my first sight of a Polynesian island. I did not expect, of course, to find the classic coconut palms and hibiscus, for I knew that the island was without trees or shrubs, but I certainly had not imagined that this outpost of the sunny islands in the South Seas would remind me, as it did at once, of the coasts of Sweden and Norway. When the cruiser on which we had made the voyage anchored off Hangaroa, the only modern village on the island, memories of Scandinavia came even more vividly into my mind as I examined through my field glasses the frame houses of the natives, which are of a type common in northern Europe. The capital of the legendary Easter Island looked, for all the world, like a humble fishermen's hamlet seen in a fog on the Baltic.

I shall never forget that first day when we were anchored just off the little harbor. Gusts of wind drove long rollers against the shore with such force that they broke amid spouts of spray with a deep pounding. In front of the sandy cove, the waves piled up over a bar that, it seemed, nobody could cross. The natives gathered on the beach did not appear very eager to meet us, but the *karanga*, the cries which announce any important event, had sounded in the village, and from everywhere, on all the paths leading to the sea, we could see men on horseback coming at full speed. Near the boathouses a palaver was held, and on the outcome of that everything depended. The commander of the cruiser had decided that on no condition would he put us and our 90 boxes of equipment ashore. Our only hope for an immediate and safe landing lay with the natives.

Suddenly we saw them rush to the boathouses, drag three canoes toward the sea, jump into them and disappear in the surf. We held our breath, expecting the canoes to capsize in their attempt to cross the bar. But after a short time, one, two, then all three surged up from the wall of water and headed toward our ship. The men were received with cheers, a well-deserved tribute to their courage and skill.

When the canoes reached our ship we saw that they were full of natives wearing the most surprising disguises. The majority were dressed in old uniforms of the Chilean navy. In one canoe there were, it appeared, lieutenants, admirals, surgeons, and engineers. A few had also put on feather headdresses, similar to those in which their ancestors had received Captain Cook, but they wore them merely as an advertisement of the native wares of all kinds which they wished to trade for shirts and sailors' caps.

Each time I find myself using the word "natives" for the modern inhabitants of Easter Island, I have a hesitant feeling, just as hesitant as on that day when I first saw their faces over the railing. I

could not decide whether these men were a heterogeneous crowd of European beachcombers or real Polynesians, the sons of the sea rovers who had colonized the island. That European blood flowed in their veins, there was no doubt. Some of the men who came aboard and tried to sell their curios looked decidedly French; others might almost have had brothers or cousins in Hamburg or in London. Yet there was something exotic in all of them and traces of old Polynesian descent could be seen in their black, wavy hair, in the strange, vivacious dark eyes, in the high foreheads. These first Easter Islanders whom I met impressed me as of mixed race. Later, genealogical investigations showed that only a third of the present inhabitants could claim descent from a pure Polynesian ancestry—and the claims were not always well attested.

There is one misconception about these people which should be dispelled. It has been stated over and over again that the modern Easter Islanders are a degenerate population and that they can have nothing in common with the people who carved the statues and inscribed the tablets. This is not true. They appeared to me in many ways to be highly gifted.

During the 6 months I spent on the island, I found myself compelled to admire their ingenuity and their remarkable talent for assimilation. No European village has given me the impression of more intelligent adaptation to a changing world. This capacity is doubtless responsible, in part, for the passing of the old culture. Though the most isolated people in the world, the Easter Islanders are constantly on the lookout for new ideas, new fashions—and also new vices. Their extraordinary faculty for exploiting any weakness or interest in their visitors has had some amusing results. For example, a few years after the missionaries came to the island, the natives started to speculate on the antiquities and on the mysterious past of their little country. Finding that foreigners were interested in the small wooden images of emaciated figures which had been one of their forefathers' greatest artistic achievements, they proceeded to produce crude imitations by the hundreds. The modern craftsmen are without illusion as to the perfection of their work, but they excuse themselves by saying: "Why should we bother about beauty and finish when our patrons don't discriminate between good and bad images and we get in exchange the soap and clothes we want?" Thanks to this commercial instinct, several of their old industries have been kept alive.

One of their greatest and most profitable activities is palming off on amateur archeologists rough stones alleged to be ancient artifacts or well-made imitations of them. The very day of my landing a native cynically proposed to cooperate with me in faking old imple-

ments and works of art. His idea was that since I had books and photographs showing the designs and he had the manual skill we might form an ideal, not to say a profitable, partnership. I must confess that on several occasions the islanders' skillful imitations completely deceived me, and I thus acquired a beautiful collection of ancient stone hooks that I only gradually realized were modern copies.

This continued practice of the traditional arts has a certain historical bearing. It suggests that there has never been a complete breach in Easter Island civilization and that the present natives, however mixed in blood they may be, are, nevertheless, the successors in direct line of the unknown men who carved the old wooden images that are nowadays prized specimens in our museums.

Unfortunately, this is not the only old custom which has survived. From the time when the Dutch discovered the island to the present, its people have had the reputation of being the cleverest thieves in the South Seas, and quite rightly. This complaint is repeated in all the accounts of the early navigators, and many of the dramatic incidents on the beach of Hangaroa have arisen from the natives' brazen contempt for the sanctity of private property. Only the sensitive and elegant French explorer La Pérouse adopted the policy of laughing at such pilfering, and paid no further attention to it. He and his men were amused by the attitude of the native women who helped their mates pick pockets by distracting the attention of innocent victims through entreaties and "ludicrous gestures."

The natives of our day are just as thievish as their forefathers, and this wayward disposition is the cause of endless troubles for the English company which has leased the island from the Chilean Government for sheep raising. To prevent constant stealing of the sheep the company put barbed wire across the island in an attempt to force the people to remain within the bounds of their village. But such drastic measures were of little avail, and in the year I spent there 3,000 sheep disappeared. Though the culprits are known to the whole community, family loyalty protects them and makes investigation useless.

Otherwise the natives are law-abiding and peaceful; there are very few records of murder or bloody violence among them. The only criminal we heard of was one of our guides, who, ironically enough, proved to be about the only honest man on the island.

The people live as they did in the past, on the produce of their fields. Taros, sweetpotatoes, yams, bananas, and sugarcane grow abundantly on the fertile volcanic soil. The only wants they cannot supply themselves are for manufactured goods such as soap. And they like especially to get foreign clothing. In this matter, the men

do well for themselves by barter with the white sailors who visit the island, but the women cannot be so provided for. They complain bitterly of the difficulty they have in satisfying their coquettish taste.

For an anthropologist, the material on Easter Island is rather scant. The old culture has nearly gone. No Westerner ever saw it while it was still functioning. The data on the past, which can be gathered, are limited to statements or tales which a few people have heard from fathers or grandfathers. Nevertheless, I was surprised to find a relatively rich folklore, which helped me to understand many aspects of the ancient civilization. Both legends and anecdotes stress cannibalism, which seems to have haunted the imagination of the Easter Islanders before the arrival of Christianity.

Those who expect to find in these traditions any evidence for the existence of a civilization previous to that of the Polynesians will be sadly disappointed. There is not a single feature of the Easter Island lore that does not point toward Polynesian origin. The language itself is pure Polynesian, and no words now in use hint of a legacy from any other linguistic stock.

These are the main facts to bear in mind as we turn to the problem posed by the mysterious gigantic statues and the inscribed tablets. But before we go into it, we must first consider what is to be said of the theory that the island is a peak of a sunken continent, since upon this assumption the classic interpretation of its mysteries has for a long time rested. There is no scientific evidence that Easter Island is the wreckage of such a sunken continent—Lemuria or Atlantis. It is plainly a typical volcanic island of recent origin, formed by a series of eruptions originating on the floor of the ocean. Soundings have revealed a depth of 1,770 fathoms 20 miles from its coast. Moreover, when the island was settled by Polynesian migrants it does not seem to have been much more extensive than it is now. Its coasts are subjected to continual erosion from the waves, and it is true that during the last decades a few of the monuments which once stood on the top of a high cliff have been precipitated into the sea. But since the ancient sanctuaries were erected along the shore, if the erosion had been very great, all of them would have been washed away by now. There has also been a question about a great road which, it is said, ran to the shore of the island and continued under water, suggesting that the shore was once much farther out. The famous French writer, Pierre Loti, was, if I am not mistaken, the first to mention this "triumphal avenue," which he thought would lead to the heart of the mystery. On a simple statement of this traveling poet visions of submerged glory have been based, and many good minds have allowed their imaginations to follow the submarine road down to enchanted palaces. The truth is that no such road exists. What Loti took for

a paved highway is seen on close examination to be only a bed of lava that in its flow reached the sea.

Other writers, abandoning the hypothesis of the sunken continent, have advanced the view that Easter Island is the center of an archipelago which vanished beneath the waves in a great cataclysm not so many centuries ago. They suggest further that the inhabitants of this supposed string of islands had used Easter Island as a burial place for their dead. According to this surmise, the dream Land of Davis would have been among the many islands that were submerged. But no geological facts can be found to support this theory either. We know, too, that the sanctuaries of Easter Island continued to be used as burial places by the islanders as recently as 70 years ago. Ruins of old villages near the monuments are added evidence that this speck of land was inhabited by the living in former times as it is today, and that it could not have been merely a mausoleum.

However, there remains the baffling fact that such a diminutive island is covered with great statues, some of them 30 or 40 feet high and weighing many tons. Despite my skepticism about the elaborate theories offered in explanation of this miraculous flowering of sculpture, I must confess that I, too, like all previous travelers to the island, was overwhelmed by a feeling of astonishment and awe when I first saw them.

There are few spectacles in the world more impressive than the sight of the statue quarry on the slopes of Ranoraraku. The place is indeed sinister. Imagine a half-crumbled volcano, a black shore line, and huge cliffs which rise up from the sea with smooth green pastures above them. Guarding the quarry, near the volcano, is an army of giant stone figures scattered in the most picturesque disorder. Most of them still stand out boldly. Successive landslides have partially covered others, so that only their heads emerge from the ground, like those of a cursed race buried alive in quicksand. Behind the rows of the erect statues, along the slopes of the volcano, there are 150 figures still in the process of being born. Wherever one looks in the quarry, one sees half-finished sculpture. Ledges of the mountain have been given human shape. Caves have been opened in which statues rest like those on medieval sepulchers in the crypt of some great cathedral. Hardly a single surface has been left uncarved by the artists in their frenzy to exploit the soft tufa of the mountain.

There is something weird in the sight of this deserted workshop with the dead giants all about. At every step, one stumbles over discarded stone hammers. It is as if the quarry had been abandoned on the eve of some holiday, and the workers were expecting on the day after to return and resume their tasks; indeed, in several cases, only a few more blows would have been needed to cut the statues finally free from the rock of the slope.

In my opinion, the seemingly sudden interruption of work in the quarry is the most puzzling problem presented by Easter Island. Such an abrupt stoppage in the sculptors' activity suggests some unforeseen catastrophe, some extraordinary event which upset the entire life of the place. The natives have always had the idea that magic was at the bottom of the trouble whatever it was. There is a legend among them that an old sorceress, forgotten perhaps at a feast, may in her rage have put a curse on the quarry which frightened the workers forever away.

If we reject this fabulous story, we have no explanation of the phenomenon for which there is any basis however slight. Was there possibly some surprise attack by a hostile group on the island in which all the skilled stone carvers were killed? Was there an attack from chance invaders? Were the natives suddenly overwhelmed by a violent epidemic, or did something about their first contact with white men cause them to lay down their tools once for all? We do not know the answer, and I doubt if we shall ever have any light on it.

Whatever the truth about the end of their work, it appears that the last of the stone carvers were under the spell of a megalomaniac dream. Some of the unfinished statues are of enormous size, one of them 60 feet tall. Others are to be found in places out of which it seems impossible that they could ever have been taken. Perhaps their sculptors never intended to move these isolated giants.

There are two types of Easter Island statues—those which still stand in the crater or at the foot of the volcano Ranoraraku, and those which once surmounted the *ahu* or burial places. Though they are of the same stone and of the same general style, there are differences which are worth stressing.

A word must be said about the burial places, which were situated at frequent intervals all along the shore in a line that encircled the island. Most of them were huge stone structures of a peculiar plan developed from the primitive cairn. In these large mausoleums, the crude heap of stones has evolved into a real monument through the use of a retaining wall. This wall, which formed a façade always facing seaward, was built of slabs or regular blocks of stone carefully fitted together into beautiful, smooth surfaces. Behind this is a level platform, and then a gradual slope backward, filled in with coarse rubble. The central portion of the façade juts out, like the apron of a stage, and on the top of this projecting part of the platform stood a row of statues with their faces turned inland. In the long slope leading up to this sacred place the dead were buried.

The figures of the mausoleums or sanctuaries were in the nature of huge busts, the head being disproportionately large in relation to what appears of the body. The back of the head goes straight up from the shoulders and, with the vertical lines of the ears, gives the head a

flattened appearance. The eyebrows are well marked and overlap the elliptical cavities which represent the sockets of the eyes. The nose is long, the tip slightly upturned and the nostrils expanded. The thin lips are pursed with what seems a scornful expression. The arms, slightly flexed, cling to the bust with the hands joined over the abdomen, below which the figure is cut off.

The other sculptures on the island—the lonely images on the plain and those that guard the slope of the volcano Ranoraraku—have the same features except that there are no sockets for the eyes. This part of the face, as in some modernistic sculpture, is defined only by the ridge of the eyebrows and by the flat plane of the cheeks below. The lower part of these statues tapers to an enormous peg, which was sunk into the soil.

The function of the *ahu* images can be surmised from analogies with the rest of Polynesia. The old Marquesans, close relatives and perhaps forebears of the Easter Islanders, adorned their stone platforms with statues which represented their ancestors. Among all the natives of central and marginal Polynesia, there is the same tendency to give human form to ancestral gods presiding over the sacred places. In the sanctuaries of central Polynesia stood huge slabs that were erected in the same position as the Easter Island statues. These slabs were receptacles for the souls of the ancestral gods, who entered them when they were called by the priests. The Easter Island statues are merely a more realistic development of this idea, favored by the existence of easily carved tufa deposits. Their sculptors elaborated rather than originated a tradition.

Everywhere on the island statues are to be found: on top of volcanic hills, along cliffs, and in places which seem almost inaccessible. Their mass must have made their transportation difficult. As a matter of fact, no one has yet explained how some of them were hauled from the quarry and then erected on the platforms on the opposite side of the island.

Of course, there are many other instances of people with rudimentary equipment moving objects of great size—for instance, the dolmens and menhirs of Europe. As the statues that the Easter Islanders erected on their sanctuaries were of the native tufa, they were not exceedingly heavy for their bulk. Their weight ranges from 5 to 8 tons; only one weighs as much as 20 tons. But because the rock from which they were carved is soft, it must have been necessary to take innumerable precautions not to mar or break them in transit. This would have been easy if abundant supplies of wood had been accessible, but, except for a few bushes, the island seems always to have lacked wood. Good material for making ropes was apparently also lacking. The only thing they could have been made from is paper

mulberry, which the natives grew in special stone-enclosed plots. Perhaps the wood necessary for making sledges on which the statues might have been hauled was lumber that floated ashore. This is frequently mentioned in ancient tales. If native timber or driftwood was available in the old days, the difficulties of transportation would not have been overwhelming. We know that other Polynesians transported objects quite as heavy as the Easter Island images. For instance in the Marquesas, slabs weighing as much as 10 tons were hauled along the slopes of the mountains. The famous doorway, or trilithon, of Tonga, which is one of the marvels of the world, has a lintel weighing 30 tons. But when the Easter Islanders of today are asked about the means by which the statues were transported, they only say: "King Tuu-ko-ihu, the great magician, used to move them with the words of his mouth."

Other questions have arisen about the Easter Island carvings. How, for instance, did the people get the manpower for such large enterprises, which would have been impossible, it seems, if the population were as small as it is today? The answer is that before the Europeans arrived, the island had ten times as many inhabitants as it now has—4 or 5 thousand would be a conservative estimate. We know this from data given by its first European visitors and the early missionaries.

Again, are these statues as old as has been said? Certain writers have dated them as far back as 1000 B. C. There are even some who think that they might have been in existence 10,000 years ago. But the weight of general evidence is against these views. Although their material is a relatively soft stone, they still retain sharp outlines, and the hammer marks are still noticeable on them. As the winds blow with relentless force over the island, and rains are both frequent and violent, if the carving had been done thousands of years ago, it could not be in such good condition as it is today. Tradition seems to indicate that the Polynesian ancestors of the present inhabitants came to the island and settled it in the twelfth and thirteenth centuries A. D. All things considered, I do not think the statues can be more than five or six centuries old. But no definite date can be set for them.

The figures of stone that stood so high above the shores of Easter Island, and in such striking formation that it is no wonder they amazed the old navigators, have attracted more attention than the other mysterious objects to which I have already referred—the wooden tablets with rows of strange signs incised on them. But these curious pieces of wood have also given rise to much speculation. They were bought from the natives by the missionaries in the early days of their work, and ever since they have been thought to contain a real script which, if it could be read, would prove a key to the island's mysteries.

The first white man to discover the tablets was Monseigneur Jaussen, French Bishop of Tahiti, in 1866. As he was looking at a piece of

wood, wrapped around with strands of hair, which a missionary had brought from Easter Island as a gift from the natives to the head of their new church, he was puzzled by the rows of small designs he noticed on it. These he took to be hieroglyphs, and his view has been shared by all the later students of the problem. The so-called "hieroglyphs," cut in the wood with a shark's tooth, are realistic or conventionalized drawings of various subjects, including apparently geometrical figures. Many of them represent men, animals, plants, and other familiar forms reduced to their essential features with no unnecessary detail to blur the image. They run up and down the tablets in rows so arranged that when the reader arrives at the bottom of one row, he has to turn the tablet upside down to see the designs of the next one in a normal position. These images, or characters, are among the masterpieces of primitive graphic art that have come down to us. They are outlined with an exquisite grace. The symbols are uniform in style suggesting an established and highly developed aesthetic tradition.

Unfortunately, the discovery of this remarkable work was not followed up by scientific inquiries at a time when they might have borne fruit. When, finally, in 1914 Mrs. Katherine Routledge, the distinguished English anthropologist, tried to obtain a key to its meaning from the last native who had been trained in the old chanters' school, it was already too late. He died of leprosy a few days after his first interview with her. The modern natives know nothing of the matter. They tell merely vague tales of the tablets, saying that they are magical objects which have the power to cause death.

The supposed substance of the rows of designs on some of the tablets was dictated in the Easter Island dialect to Jaussen by a native named Metoro. But when Metoro's words were translated it appeared that they were only a simple description of the designs, not their actual content, as had been hoped.

Other attempts at interpretation have been undertaken but with even less success. The most serious was that of an American naval officer, W. J. Thomson. In 1886 he tried to obtain the text of what was inscribed on the tablets from an elderly native. This man undoubtedly had some knowledge of the characters, but he had become a good Christian and was afraid of jeopardizing his chances in another world by touching the tablets or even looking at their pagan symbols. In order to resist the temptation, he ran away and hid in a cave, where Thomson finally captured him. There he was "stimulated" by flattery and a few drinks to what was thought to be a revelation of these secrets of the past. At any rate, he began to chant old Polynesian hymns, which he said were the texts of the tablets. Thomson and his colleagues noticed, however, that their informant was paying no atten-

tion to the rows of designs as he chanted and did not repeat his words when the same tablet was put into his hands a second time. He was, therefore, thought to be a fraud and was dismissed.

As I have already said, a definite clue to the enigma of this so-called "script" seemed at last to have been discovered 7 years ago, when Mr. de Hevesy pointed out a series of analogies between some of these Easter Island designs and those of an old Asiatic script found on stone and clay seals in the ruins of two forgotten cities, Mohenjo-daro and Harappa, in the valley of the Indus. Now, archeologists agree in thinking that the civilization of the Indus region dates from about 3000 B. C. Its people were an unknown race that knew how to build planned cities with a complicated sewerage system. The script they used is still undeciphered, but hypotheses about it have been advanced which, if substantiated, would make it one of the earliest known forms of man's writing. Some Orientalists see striking analogies between this Mohenjo-daro script and the early Chinese hieroglyphs.

Although the relationship between Easter Island "script" and that of the Indus has been accepted widely as a demonstrated fact, I cannot help being skeptical for several reasons. The Indus civilization, contemporaneous with that of Sumeria and Egypt, was extinct by 2000 B. C. Easter Island culture died out only 80 years ago. Roughly 15,000 miles of land and sea separate the Indus Valley from the island. Between them lie India, Indonesia, and enormous wastes of water. In other respects Mohenjo-daro and Easter Island have nothing in common: the arts of the Indus, like weaving, pottery, and metal working, were unknown to the remote islanders. The proud city dwellers of Mohenjo-daro would have looked down upon the half-naked people who lived in thatched huts, and indulged in cannibalism. How could two such different and widely separated peoples have shared the same form of writing?

In order to answer this question, Mr. de Hevesy advanced the theory that the Easter Island tablets are many centuries, if not millenniums, old and were brought to Easter Island by the first immigrants. Here the evidence that remains is against him. The wood of the best and largest Easter Island tablet is that of a European oar. Besides, if Hevesy's theory were to be accepted we should have to make the difficult assumption that the Easter Islanders kept their script unchanged for more than 5,000 years. A careful analysis of the tablets and the Indus script has not borne out this theory. True, some of the signs in the Indus script have striking analogies with those of Easter Island. I am, nevertheless, still more impressed by the divergencies, and by the doubtfulness of parallels based only on a few cases which take no account of many variants of the same design.

Moreover, there is little question, I believe, that the designs on the tablets were created by natives of Easter Island. It would be difficult to explain on any other assumption the presence among them of so many figures of animals belonging to the local fauna and of objects that are found, as far as is known, in its culture only. Mr. de Hevesy interpreted certain of the Easter Island symbols as representations of monkeys and elephants, but for these suggestions of India's jungle life he drew on his imagination.

In the hope of throwing some light on the mystery, I applied to several tablets an analytical method. I counted their symbols and studied their combinations to find out whether they might constitute an actual script. If the symbols represented sounds, the same signs would have been combined in the same order whenever a word was repeated. But this seldom happens. The same combinations of the same symbols recur in only a very few cases. The individual designs are repeated over and over again but apparently in haphazard order. No clue to a script came from this study.

If we might assume that the tablets contain an actual script, the question would arise whether it were pictographic or ideographic. To answer this there are not enough different symbols. Most of them are variants of about a hundred fundamental designs. On certain tablets the same signs form a high percentage of the total.

Assuming that the Easter Island tablets contained a script, I thought it likely for a long time that this was based on the same principle as the designs inscribed on birchbark by the Ojibway Indians, who record charms by means of figures which sometimes remind us of the Easter Island symbols. From the images drawn on bark, the Indian shaman reads a text which, to his mind, they represent. The Cuna Indians of Panama still use the same primitive form of writing.

But one thing made me suspicious of such an interpretation. The Easter Island tablets are pieces of wood of various odd shapes which are always covered with designs from one end to the other and on both sides. If their contents corresponded to a script text, this would mean that the artist always knew in advance just the size and shape of the piece of wood his chant would fill. As this seemed highly improbable, I was obliged to abandon this entire hypothesis and seek for some better clue to the mystery.

I found it in a link that has been kept between the tablets and the oral traditions, songs, and prayers of the Easter Islanders. The very word that the natives use for the tablets puts us on the right track.

They are called *kohau rongorongo*, which means literally "orator staff"—that is, the stick, sometimes decorated with carved symbols, sometimes not—which a speaker holds in his hands while making a public address or reciting a piece of traditional lore, as if to give added significance to his words. The *rongorongo* were professional chanters

who formed a society, which existed not only on Easter Island but also on other Polynesian islands. In childhood they were taught in special schools to memorize and to recite the lore of their tribe.

Everywhere in Polynesia the chanters use such an "orator staff." Sometimes, as in New Zealand, the staffs are provided with notches, which are supposed to help in reciting genealogical tables. In the Marquesas, the chanters held, while chanting, a bundle made of string wound about with knotted ends hanging down, which was thought of as containing the substance of the chant though the connection between the words and the contents of the bundle was loose. The bundles symbolized the chants and were in consequence of paramount importance. They were solemnly given to the young people after they had been initiated into the lore of their ancestors.

These facts, I concluded, give us the best clue in the problem of the Easter Island tablets. To its chanters as to the chanters of other islands, the "orator staffs" were the accessories and the symbols of their function. Originally, the designs on the staffs or tablets might have been mnemonic, but later on they lost their exact significance in the minds of the natives and were looked upon merely as simple ornaments or magic symbols. It may be added that even now we can observe on Easter Island a slight relation that has been preserved between design and chant. The natives are in the habit of chanting when they make string figures or cat's cradles. This interpretation of the tablets may not contain the whole truth about them. I offer it rather as the hypothesis which best fits the facts available today, and which harmonizes also with what we know of an underlying tendency in Polynesian civilization.

But these are not all the questions that have been raised by Easter Island. Some observers have found in the well-carved and well-fitted stones of its sanctuaries likenesses and relations to the ancient remains in Peru, and to account for them have said that there must have been intercourse between these two parts of the world at some period of history. But close study has revealed that between the Peruvian and the island ruins the resemblances do not go beyond the general fact of an exact fitting of the stones. The plan and the structure of the Peruvian buildings are entirely different. In Peru the walls are all of carved stone blocks, whereas in Easter Island they consist of slabs set on edge outside with rubble behind. The only conspicuous architectural achievement of the Easter Islanders was to select the slabs and to dress their corners so that no gap would appear on the surface and impair the general appearance. This they could naturally have learned to do without crossing the Pacific in frail canoes and making the long journey inland to the site of the wonderful ruins in Peru. Moreover, these are certainly far older than the Easter Island sanctuaries. Thus it seems clear that we must

give up hope that the remains on Easter Island will help to solve the problems of early American civilizations.

The result of 3 years' work on the island culture pursued at the Bishop Museum in Honolulu, with which I have been associated, shows that this Ultima Thule was discovered and settled by Polynesians, who arrived in a fleet of double canoes sometime, roughly, between the middle of the twelfth century A. D. and the end of the thirteenth. The time of the discovery and settlement can be established approximately from the lists of chiefs that have come to us. These the early missionaries took down from the dictation of the natives. I was permitted to copy another one from a list which my native informant had compiled himself. Many errors have, of course, slipped into these records, but a comparative study of them shows that Easter Island has been ruled by about 25 or 30 chiefs since the founder of the dynasty, Hotu-matua, and his people first came to its shores. Allowing 25 years for each ruler's reign—the usual method of measuring time in Polynesian annals—we find that this must have happened very close to the twelfth or thirteenth century. From other sources, we know also that this was a period of great sea expeditions, and that the settling of New Zealand and of many other islands in the Pacific occurred in what seems to have been a heroic age of ancient Polynesia.

Curiously enough, the oral tradition of the migration to Easter Island has been preserved remarkably well even down to the present. While I was there, I was told in great detail many more or less legendary incidents of the voyage eastward of Hotu-matua and his associate, the noble Tuuko-ihu. These stories with their core of history were the glorious sagas of the first emigrants to this little lost world.

At about the same time, the Tahitians, Maori, and Marquesans had a culture which was still undefined but was very similar in the different groups. In the course of the succeeding centuries, over each of these island areas a civilization developed along original lines, though still retaining the common background. The Easter Island culture belongs to this purely Polynesian type. The ancestors of the present population merely improved upon the legacy they received.

Where then did the Easter Islanders come from? Since they are Polynesians in race, language, and culture, the problem of their origin coincides with that of the Polynesians as a whole and is as yet unsolved. That the Polynesians came from Asia is beyond doubt. India, Assam, and Indo-China have been variously given as the cradle of these seafaring tribes, but sufficient evidence to validate these theories is still lacking. Within the Polynesian world the Easter Islanders offer many analogies with the Maori of New Zealand, the people of Manga-*reva* and those of the Marquesas. Actually the resemblances between Easter Island culture and that of the Marquesas are very striking. It

is possible that the Easter Islanders were among the early Polynesian emigrants who spread from central Polynesia toward the east, occupying the Tuamotus, Mangareva, and the Marquesas. Very likely after a sojourn in the Marquesas some again sailed eastward and discovered Easter Island. At the time they left the Marquesas their culture, of course, had not yet developed the specific pattern which characterized it when the Europeans landed there in the eighteenth century.

The genealogies of Mangareva, the nearest Polynesian island to Easter Island, date back to the twelfth century, but traditional history mentions early immigrants who settled on these islands and then left for other countries, leading a restless life. Similar traditions exist among the Marquesans. Hotu-matua, the discoverer of Easter Island, and his followers may well have represented a defeated tribe or a junior branch of the Marquesas or Mangareva.

What remains today of their work is evidence of the beauty and greatness of their isolated civilization, revealing the vigor and audacity of these Polynesians who spread over what seem once to have been the happiest islands on earth.



1. SEAWARD FACADE OF AHU (BURIAL PLATFORM) TE-PEU.
Notice in the structure pitted slabs taken from house foundations.



2. THE SEAWARD FACADE OF AHU VINAPU, THE BEST STONE STRUCTURE OF THE ISLAND.



HALF-BURIED STATUES ALONG THE SLOPE OF VOLCANO RANO RARAKU.



1. GROUP OF PETROGLYPHS ON TOP OF VOLCANO RANO-KAO, AT THE PILGRIMAGE SITE OF ORONGO.

They represent the bird-man holding the sacred egg.



2. TEPANO, THE BEST INFORMANT OF THE ISLAND, CARVING A WOODEN IMAGE IN THE STYLE OF THE FAMOUS MOAI KAVAKAVA.

Modern specimens are crude as compared to the masterpieces of ancient art.



1. VICTORIA RAPAHANGO, ONE OF THE LAST DESCENDANTS OF THE KINGLY FAMILY, PEELING PAPER MULBERRY STEM TO MAKE BARK CLOTH.



2. NATIVE GIRL BEATING PAPER MULBERRY BARK TO MAKE A FABRIC.

BRAIN RHYTHMS¹

By E. D. ADRIAN, O. M., F. R. S.
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In 1929 Prof. Hans Berger, of the Psychiatric Institute at Jena, published the results of some work on which he had been engaged for many years. He had set out to record the electric currents developed in the human brain, and had shown that if metal electrodes were fixed to the scalp, it was possible to detect a regular oscillation of electrical potential which was not due to muscles or skin glands or any other source outside the skull, and could only have come from the nerve cells of the cerebral cortex. The oscillation had a frequency of 9-10 a second. It only appeared when the subject was at rest with attention relaxed and eyes closed; but it obviously represented some kind of continuous activity in the brain covering a fairly large area. What he discovered was then quite unexpected. It has made us revise many of our ideas about the brain and has brought us a little nearer to understanding what goes on in it.

The oscillation, Berger's α rhythm, represents a very small change of potential, about 50 microvolts, and a very small ebb and flow of current in the cerebral cortex. There is nothing unexpected in the fact that brain cells develop small currents when they are active, for all active cells do so. The unexpected thing is the regularity of the rhythm. It is true that if it were not so regular it might never have been detected, but the regularity means that large numbers of brain cells must be working in unison at the same rate. We should have expected something much more complex and variable—activity varying from moment to moment and from place to place—and not the uniform pulsation shown in a typical record of the electroencephalogram.

We should have expected this because the brain is a great sheet of nerve cells and interlacing nerve fibers, and its working must depend on the spatial distribution of activity in it. This is determined by the particular pathways which must be taken by the incoming and outgoing messages, for the messages are all in the same form wherever they come from and it is because they arrive in different regions that

¹ Friday Evening Discourse at the Royal Institution delivered on February 4, 1944. Reprinted by permission from *Nature*, vol. 153, March 25, 1944.

we interpret one as sight and another as sound. We know, for example, that if one looks at a bright cross, the initial event in the brain will be the activation of a more or less cross-shaped area at the back of the occipital lobe, and that if one hears a sound a pattern will be reproduced in the temporal lobe corresponding to the areas of vibration in the cochlea. All the external events of which we are aware are recorded as spatial and temporal patterns of excitation in the sense organs. These patterns are reproduced in the brain with a good deal of editing, omission of details and heightening of contrasts, and it is from them that we reconstruct our external world.

Now the α rhythm of the electroencephalogram comes from large areas in the occipital region and to some extent from the frontal area as well. At first sight this seems to leave little room for all these diverse patterns of electrical activity. But actually the regions where the potential change is at a maximum are not those where the messages from the sense organs are received in the brain, but are the neighboring "silent" or "association" areas. Also, to make the rhythm appear, the

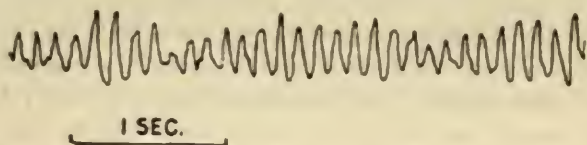


FIGURE 1.—Normal electroencephalogram showing the α rhythm. The maximum potential change is 45 microvolts.

eyes must be closed and the attention relaxed, so that the brain is relatively inactive, at least so far as vision is concerned. Thus the regular wave sequence is derived from certain parts of the cerebral cortex when these have little to do. The cells there are not concerned with the incoming signals and so will be free to beat in unison, and if fairly large areas are so beating our records from the head will show the α waves and will not show the small local irregularities which are probably going on all the time so long as we are conscious.

The cells of the cortex might beat like this when they are left alone because this is how they are made; because like heart muscle or ciliated cells they cannot remain alive and inactive; or the beat might be imposed on them by rhythmically active cells in some other part of the brain which can act as pacemaker to the association areas. Wherever the pacemaking region may be, the important fact is that the rhythm is much the same from one person to another. For clinical purposes, therefore, an electroencephalographic recording can be used as an index to show whether the brain is working normally or not, and for this reason it has become an important technique of clinical neurology. Apart, however, from the value of these records as a means of diag-

nosis, there is the problem of their significance in relation to the normal mechanism of the brain and of the mind. Do they tell us anything about the neural accompaniment of perception and thought?

The statement that one can record the electrical activity of the brain through the skull raises the hope that one should be able to detect all sorts of brain events connected with consciousness. The hope begins to fade when it is realized that the main feature of our records is a rhythm from nerve cells which are relatively inactive. But there is something of interest to be learned from them. It is true that we cannot yet record the detailed activities of different parts, but only the gross changes when a whole area goes into action; yet these do give us some novel information about the physical accompaniments of thought and in particular about the process of attention.

To begin with, it seemed that the α rhythm was much less interesting. It might have been merely a spontaneous beat of the nerve cells in parts of the cortex, particularly those concerned with vision—a beat developing whenever the cells were not stimulated by messages from the eyes. Opening the eyes would break up such a rhythm in the receiving area, because the visual pattern there would mean that different groups of nerve cells would be discharging at different frequencies. Something of this kind can certainly happen in the regions where a message enters the cerebral cortex, for in records from the exposed brain (in anesthetized animals) the arrival of a message in the receiving area produces small, rapid waves in place of the slower and larger α rhythm. But the α waves are not confined to the receiving areas of the brain, and it can be shown that in fact the presence or absence of messages from the eyes is not the essential condition for the disappearance or return of the α rhythm.

As far as vision is concerned, what really determines the presence or absence of these waves is not whether visual messages are or are not coming into the brain, but whether we are or are not attending to them—whether we are looking at anything. Man is a visually controlled animal, and if our eyes are open there is usually something in the visual field which catches our attention or some part of it. This is not true for all mammals; the rat and the cat seem to rely more on other senses and can be quite inattentive to sights. But with us the only sure method of shutting out sights from the mind is to close the eyes. Normally, therefore, opening the eyes means that we start looking, or that we become attentive to the visual field. The α waves then disappear, and they return when we close our eyes and cease looking. But shutting the eyes does not cut out all light from the retina, and the α rhythm appears in the brain however much or little light may be falling on the closed lids. Even in a pitch-black room, if we open our eyes and start trying to see something, the rhythm goes, although open-

ing the eyes cannot have altered the illumination of the retina. Sooner or later, when we have given up the attempt to see, the waves will return although the eyes are still open.

What matters, therefore, is not the excitation of the retina but the turning of attention to the visual field or away from it. This can be shown even more clearly in another way. In daylight and with the eyes open, the attention can rarely be abstracted completely from vision except for short periods; something keeps on "catching the eye" and coming into the mind, even though we have most of our attention fixed on other things, a sound or a smell, for example. The reason why the visual field cannot be completely ignored is that the picture of it in our brain has patterns and sequences which arouse interest by recalling memories or starting some new train of activity. But if we can make the visual field convey less meaning, it will cease to be so attractive and our attention can leave it more easily. A simple way of securing this is to wear spectacles which will throw everything out of focus.

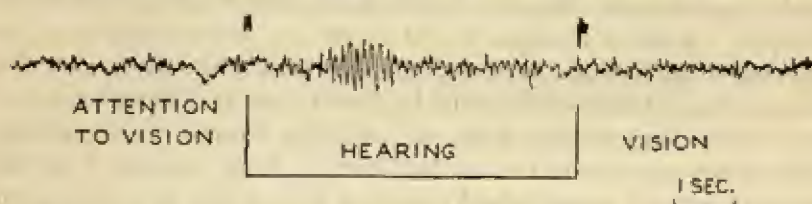


FIGURE 2.—The α rhythm appears when the attention is transferred from vision to hearing. The visual field has been made unattractive by +10 D spectacles. During the middle section of the record the attention is concentrated on the tick of a watch.

When this is done, although the eyes remain open, the α rhythm will appear much more readily than when the visual field is in its proper focus. With the field blurred, we have only to listen intently to a sound and the α waves will begin, to cease again if we transfer our attention back to vision. Here, too, there has been no change in the illumination of the retina but only the shift of attention. It may be noted that it is not only the intellectual interest of the field which holds our attention. Any movement in it or any sudden change of illumination will do so; and there is a great variation in the ability of different persons to detach the attention from vision, and in the same person at different times.

All this shows that the α rhythm is an activity which appears in the cerebral cortex when the attention is not directed to vision, and disappears when it is. The mental act of looking somehow prevents the α waves from developing in certain parts of the brain, parts which are likely to be concerned in analyzing the visual pattern. The α rhythm is therefore a rhythm of inattention, a positive activity which fills those

parts of the cortex which are for the moment unemployed. It is not the basic rhythm of unstimulated nerve cells, and there must be some kind of competition between the message from the eyes and from the source of the α rhythm to decide which shall control the cortical areas.

To examine this competition in more detail, we must have some way of recording the sensory activity of the brain as well as the α activity. All the messages which reach the cortex will produce their own electrical accompaniment, and this can be recorded well enough if electrodes can be placed on the surface of the brain. But if we can get no nearer than the scalp, the potential changes generated in any group of nerve cells will usually be obscured by those of other groups nearby, and the record will then show us nothing. Fortunately this difficulty can be overcome, in part at least, by making all the cells work in unison. This can be done, as far as vision is concerned, by making the field more or less uniform and lighting it with a flickering light. The nerve cells are then forced to work in unison at the frequency of the flicker, and we can record their electrical activity through the skull up to frequencies of about 30 a second. This gives us a method of tracing the visual messages in the brain, for by means of the flicker rhythm they can be made easy to recognize.

Provided that the flickering area is in the center of the visual field, it need not subtend more than a few degrees at the eye to give a potential oscillation at the same frequency in the occipital region. The waves are more or less where one would expect them to be, in the right occipital region if the left half of the field flickers, and vice versa. But the flicker waves are not confined to the visual receiving area: they are found also in the neighboring areas, those from which the α waves come when the eyes are closed. The flicker area is not so large as the α area, but on occasion as much as a quarter of the brain surface seems to pulsate with the flicker rhythm. The retinal messages must then have spread widely and impressed their rhythm on some of the association areas of the cortex.

Now if the eyes are open, the flicker will keep the visual attention engaged and the α rhythm at bay. But if the eyes are closed and the flickering light is thrown on the closed lids, the subject will be conscious of the flicker but the conditions will favor the α rhythm, since closure of the eyes is usually coupled with the withdrawal of attention from vision. In these conditions the two rhythms can be seen to compete for the cortex, and sometimes to cooperate if their frequencies allow of it. The flicker rate will sometimes appear in patches with the α rate in between, and if a rapid flicker is turned on suddenly the area of the brain giving the flicker rhythm may be large at first and may then shrink rapidly, giving place to the α waves but persisting longer in regions nearer the visual area. If the flicker is made equal

to or twice the α rate, we may find the two summing up to give very large regular waves. Such a combined rhythm usually takes some time to build up as the two sets of waves have to be synchronized, but there is evidently an interaction between them and a tendency to remain synchronized as long as their frequencies are not too far apart. These wave effects vary from one subject to another and there are variations according to mood, time of day, etc.; in general, the sleepier the subject the more the α rhythm will predominate, and the brighter the flicker the more persistent will be the flicker rhythm.

The interaction and interference of these rhythms shows how the cortex, or certain parts of it, may be put at the disposal of our attention. If we decide to look, or if it is decided for us by something "catching our eye," a change occurs which prevents the α rhythm from occupying the regions surrounding the visual receiving area.

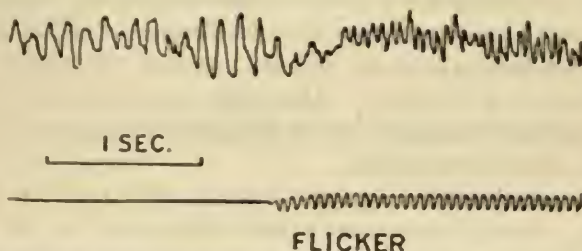


FIGURE 3.—Electroencephalogram from the occipital region, showing the change from the α rhythm to the flicker rhythm when the eyes are opened and the subject looks at a screen lit by a flickering light. The rate of flicker (17 a second) is shown by the photoelectric cell record below.

If we can turn our whole attention to a watch ticking, the α rhythm comes back. What brings this change about?

The evidence is still rather scanty. It is likely that the whole of the cerebral cortex is concerned, in that it is the balance of activity in every part which determines where the attention will turn and how long it will be held in one field; but the executive act, the direction of the attention to the particular field, is probably carried out by a relatively small central region in the neighborhood of the thalamus and near the main incoming pathways. It is from there that the α rhythm seems to be controlled, and it is at least probable that it is the sudden disturbance of this region which causes the loss of consciousness after a blow on the head. This central directing region must act on information received from the cortex, for it will be all the memories and associations stirred up by a stimulus which will determine its interest, and these are presumably not aroused until the message has reached the cortex. But the central region must balance up the conflicting claims of different stimuli and

must then decide which should have the main share of the attention; its function resembling that of a central university committee which has to decide which branch of learning should be supported by the next benefaction.

The visual stimuli always get the lion's share. If they are at all interesting, the central region will suppress the α rhythm over the occipital area, so that the visual pattern has a considerable part of the cortex set free for its analysis. When the visual pattern ceases to be interesting and the attention is directed to sounds or other sensory messages, the occipital lobe is not turned over to those but is filled again with the α rhythm. This is shown very clearly in records in which the visual waves are made recognizable by the use of a flickering light, and if the flicker happens to be at twice the α rate a partial diversion of attention will be enough to give the large compound waves at the α frequency.

Apparently the occipital part of the brain is used to analyze sights, and sights only. What parts deal with the patterns aroused by sound and touch we cannot yet say. The areas seem too small to be easily detected, and must certainly be much smaller than the areas which deal with vision. On the other hand, a concentrated mental effort may sometimes abolish the α rhythm although the eyes remain shut. Presumably in this case the whole of the α area may be turned over to nonvisual activities.

There are still many gaps in the evidence, but there is much to support the view here put forward, namely, that there is a deep-seated part of the brain which contains the mechanism by which attention is directed one way or the other, and that the α rhythm is under the control of this region, if it is not directly produced by it. If this is so, it is not difficult to understand that abnormalities in the α rhythm are often associated with abnormal kinds of behavior. The most valuable application of the electroencephalogram in medicine is in the localizing of diseased regions and tumors of the brain by the change in the character of the waves. Another is its use in detecting the sudden explosive discharges of the nerve cells which occur in the brains of epileptics. But quite apart from such obvious disorder of the brain cells, the electroencephalogram may show an α rhythm which is definitely abnormal, irregular, faster or slower than usual or with odd-shaped waves, and in a significant proportion of the subjects who give such records there are abnormalities in the mental or emotional sphere which may be a serious handicap. There are, of course, many factors besides the constitution of the brain which determine whether we react like our fellows or not, but the brain is a not unimportant factor and the electroencephalogram seems to offer a means of assessing some of its deviations from the normal. It re-

mains to be seen whether its use for this purpose will have much practical value: at present the most that can be said is that if we had to appoint someone to a responsible post and had an unlimited field of candidates, it would be safer to exclude the 5 percent whose electroencephalogram showed the most unusual features.

That is a very long way from saying that the electroencephalogram can tell us how the subject will think and act. In fact the information which it gives relates to a very limited field. But the limitation arises mainly from the fact that we can only record the gross effects and not the detailed patterns in the brain. With present methods the skull and the scalp are too much in the way, and we need some new physical method to read through them. We need the "patent double million magnifying gas microscopes of hextra power" with which Sam Weller thought he might be able to see through "a flight o' stairs and a deal door." In these days we may look with some confidence to the physicists to produce such an instrument, for it is just the sort of thing they can do; but until it is available we have to confess, with Sam Weller, that "our wision's limited."

THE DEVELOPMENT OF PENICILLIN IN MEDICINE¹

By H. W. FLOREY and E. CHAIN
Oxford University

Discovery of the chemotherapeutic effects of penicillin has excited widespread comment in the lay as well as the medical press. A first-hand account of how this substance was introduced into medicine may, therefore, be of interest.

The phenomenon of the inhibition of the growth of one micro-organism by another has been known for more than 60 years, for Pasteur and Joubert in 1877 noted that anthrax bacilli were prevented from growing when certain other organisms were also present in the culture medium. To them is credited the first suggestion of using this antagonistic property of bacteria for curative purposes.

Since this fundamental observation, many examples of the same phenomenon—called microbial antagonism—have been recorded. In many cases the inhibitory effect of one microbial species on another is due to metabolic products formed by the antagonist. These products have recently been termed “antibiotics.”

The earliest attempt to introduce antibiotics into medicine was made by Emmerich and Löw in 1898. They extracted an impure material, which they termed “pyocyanase,” from old culture filtrates of *Pseudomonas pyocyanea* and showed that it had the property of causing death, or lysis, of some of the bacteria which can cause disease in man. They recommended pyocyanase for the local treatment of various infectious diseases, but it did not come into general use, although apparently it was on sale in Germany, until at least 1936.

The only other serious attempt to utilize antibacterial products for combating infection in man has been the employment of gramicidin, obtained from cultures of *Bacillus brevis*. This powerful substance was discovered by Dubos in 1939, and although it is far too toxic to inject into the blood stream it can be used for application locally to infected wounds.

In 1929 Alexander Fleming noticed that colonies of staphylococci growing on an agar plate were undergoing lysis in the neighborhood of a contaminating mold colony. Most bacteriologists would have

¹ Reprinted by permission from *Hygiene*, vol. 22, No. 4, April 1944.

passed this over, but Fleming, an acute observer with a special interest in antiseptics, subcultured the mold for further investigation. From its descendants all the penicillin in the world was produced until recently.

The mold was identified as *Penicillium notatum*. Fleming cultivated it in a liquid medium, peptone broth, and found that it produced in the broth a substance capable of inhibiting the growth of many dangerous germs, even when diluted 800 times. The active substance he named penicillin. He noted that broth containing penicillin was not more toxic when injected into rabbits and mice than pure broth and that it did not appear to be harmful to the white cells of the blood.

As a result of this, he suggested that penicillin might be a good antiseptic to apply to septic wounds, and indeed a few cases were so treated. He concluded that it certainly appeared to be superior to dressings containing potent chemicals. The observations, however, were not carried further, though Clutterbuck, Lovell, and Rais-trick made an attempt to extract the active material. As a result of their work they concluded that penicillin was extremely unstable, and they did not pursue the matter.

In the succeeding years no further interest seems to have been taken in its chemical properties or its possible application to medicine, though Fleming continued to use the crude culture medium in the laboratory as a means of suppressing the growth of certain kinds of bacteria in mixed cultures.

In 1929 one of the present authors, H. W. Florey, started work on the antibacterial substance lysozyme—another discovery of Fleming's. This substance was first discovered in egg white but is widely distributed in nature. It has the power of dissolving or killing certain species of air bacteria, though it has, unfortunately, no effect against bacteria causing disease in man.

The work on lysozyme was carried on until its purification (by Roberts in 1936) and the elucidation of its mode of action as a carbohydrate-splitting enzyme (Meyer and associates, 1936; Epstein and Chain, 1940). During the later part of this work, in 1938, the present writers decided to undertake a systematic investigation of the antibacterial substances produced by bacteria and molds, about whose chemical and biologic properties little was known.

Although the reports suggested that penicillin was an unstable substance, it was among the first chosen for investigation, since it seemed likely to be of considerable biochemical and biologic interest. In particular, it was active against many organisms causing the most destructive lesions in man, including staphylococcus. Fleming, Clutterbuck, et al., reported that under suitable conditions penicillin

activity was retained in the culture medium for some weeks. This suggested that, if appropriate conditions could be found, the extraction of penicillin from the culture medium and its purification would be possible.

For work of the scope envisaged it was apparent that results would be obtained most quickly by a team of workers, and we have been particularly fortunate in our collaborators. Dr. N. G. Heatley devised a simple and quick quantitative assay method which has proved invaluable in the elaboration of purification processes for penicillin and in similar investigations on other antibiotics. He also designed and constructed the first large-scale laboratory plant for growing the mold and extracting penicillin. Dr. A. G. Sanders later devised and built alternative apparatus for the extraction of penicillin on a larger scale. Prof. A. D. Gardner of the Department of Pathology, Oxford, collaborated throughout on the bacteriologic aspects of the work. The biologic investigations were carried out by H. W. Florey in collaboration with Dr. M. A. Jennings of the School of Pathology, Oxford; the chemical and biochemical investigations by E. Chain in collaboration with Dr. E. P. Abraham. The therapeutic trials on man were conducted first by Dr. C. M. Fletcher and later by Dr. M. E. Florey, with the help of many physicians and surgeons.

It was established that penicillin was an acid of low molecular weight, which was stable in water. In an acid medium, it was found to be quickly destroyed. It could, however, be extracted by various organic solvents, such as ether, chloroform and amyl acetate, from acid solution and was found to be quite stable in these solvents.

From the organic solvents it could be re-extracted into water by the addition of the right amount of alkali. Little loss of antibacterial activity occurred during these operations provided they were carried out quickly and the solutions were kept cold. This transfer of penicillin between solvents and water has become the basis of all the extraction processes used on a large scale by commercial firms.

By repeating the process several times and varying the solvents, a considerable purification and concentration of penicillin is achieved. On drying the final solution from the frozen state a preparation of penicillin is obtained in the form of a yellow powder which keeps its antibacterial activity unchanged for a long time. Though chemically still very impure—these preparations contain only about 10 to 20 percent of pure penicillin—the antibacterial power is great. They contain about 100–200 Oxford penicillin units per milligram, which means that when diluted from 1 part in 5,000,000 to 1 part in 10,000,000 they prevent the growth of staphylococci. Preparations of this degree of purity can be used for all clinical purposes.

Further purification presented a harder problem, since penicillin is unstable toward many reagents normally used for purification purposes. It is unstable in dilute acids and alkalis and is destroyed by many metals, such as copper, cadmium, zinc, and mercury, and by primary alcohols and oxidizing agents such as potassium permanganate. This severely limited the selection of methods for purification, but penicillin preparations which are almost pure have now been obtained.

The purest material obtained in Oxford has an activity of about 1,000 units per milligram, corresponding to an inhibitory power against the staphylococcus of about 1 part in 50,000,000. Pure crystalline sodium penicillin has been obtained. It contains about 1,670 Oxford units per milligram. By international agreement the International Unit is the specific penicillin activity contained in 0.6 microgram of pure penicillin II (or G). The unique feature of penicillin, when compared with other antibacterial substances, is that it combines this astonishingly high antibacterial activity with a very low toxicity. An amount several hundred times greater than the therapeutic dose can be injected intravenously—into mice—without any noticeable toxic effect.

This lack of toxicity is also observed with less pure preparations, and it may indeed be counted as extremely fortunate that none of the numerous contaminating substances causes harmful effects, even when the dose of penicillin is large—far beyond that necessary for therapeutic purposes. For this reason it is unnecessary to subject penicillin to the elaborate and difficult purification processes before it can be used for clinical purposes.

After the low toxicity of penicillin had been demonstrated on mice, a more extended study of its biologic properties was undertaken. It was shown that a concentration at least a hundred times greater than that necessary to stop the growth of sensitive bacteria was harmless to the white cells of the blood and to tissue cells grown in glass vessels. The very low toxicity of penicillin to the white cells of the blood was of particular importance, as these cells play an important part in the defense of the body against invading bacteria, which they have the power to ingest and destroy.

Further research has shown clearly that when bacteria are put in nutrient media in which they can divide, then penicillin will kill them. If they are in such a condition that they cannot divide, then penicillin does not kill them.

It was further shown that penicillin is readily absorbed from an intramuscular or subcutaneous injection and from the small intestine. Once absorbed in sufficient quantity, a simple test demonstrates that it is present in the circulating blood. Unfortunately it cannot be given by mouth, because the acid of the stomach would destroy it

before it reached the intestine. It does not pass from the blood into the cerebrospinal fluid. Penicillin was shown to be rapidly excreted in the urine, the bile, and to some extent in the saliva of animals. In man also, excretion in the urine is very rapid, and this explains why the doses have to be not only large but frequent. To keep a high concentration of penicillin in the blood is like filling a bathtub with the plug out.

Another important observation was that the antibacterial action of penicillin is not diminished in the presence of blood, pus, and tissue constituents. This is in sharp contrast to the sulfonamide group of drugs, whose activity is much lower when pus is present, and which therefore have relatively little effect in suppuration.

The disease-producing bacteria which are affected by penicillin make an impressive list. Many of them are sensitive to just as high a dilution as the staphylococcus. Some are present in nearly every war wound, so that the interest of the armed forces in penicillin is readily understood. This list is by no means complete. There have been some additions to the list of sensitive organisms, the most important of which—the *Treponema pallidum*—is that causing syphilis. This means that syphilis becomes one of the diseases which can be treated by penicillin.

Bacteria affected by penicillin

Sensitive:

- Streptococcus (childbirth fever and many cases of serious sepsis).
- Staphylococcus (boils, carbuncles, and serious infections of bone and other organs).
- Pneumococcus (pneumonia).
- Anthrax bacillus.
- Diphtheria bacillus.
- Actinomyces ("woody tongue" of cattle and sometimes human disease).
- Tetanus bacillus.
- Bacilli of gas gangrene.
- Gonococcus (gonorrhea).
- Meningococcus (spotted fever).

Partially sensitive:

- Typhoid bacillus.
- Gaertner's bacillus (food poisoning).
- Vibrio El Tor (cholera-like disease).

Insensitive:

- Tubercle bacillus.
- Plague bacillus.
- Cholera bacillus.
- Brucella (undulant fever).
- Colon bacillus and related organisms.

By all these methods penicillin was shown in the laboratory to be an extremely powerful antibacterial agent with low toxicity. The proof that it had chemotherapeutic properties, that is to say, that it would cure disease in living creatures, was also first supplied in the laboratory by what are known as "mouse protection tests." Mice were

infected with bacteria which would certainly cause their death unless some successful treatment could be given.

Streptococcus, *staphylococcus* and *Clostridium septicum*—a gas gangrene producer—were all used on a group of mice, and in each case adequate doses of penicillin gave complete protection without any toxic effect on the animals. A new chemotherapeutic drug had been discovered.

The whole of the work on penicillin has been dominated by lack of material. The mold produces very small amounts of the active substance, and it is a formidable job to grow it on a large enough scale. In addition, the penicillin may be lost if the bacteria universally present in the air contaminate the culture, for they produce a ferment which destroys penicillin. A man is 3,000 times larger than a mouse, and many months elapsed between the trial on mice and the first injection in a man, while we struggled in the laboratory to produce enough material.

The first injection of a small quantity of crude penicillin into man showed that something was present which caused a rise of temperature. Fortunately, this pyrogenic substance was an impurity and not the penicillin itself, and further chemical purification removed it.

In the first two patients ever treated the amount of penicillin required was underestimated, and though improvement occurred, the disease was not cured, and there was no more material with which to proceed. However, these two patients gave a good indication of the amount required.

It has been possible to find out the dosage and method of administration, and with this knowledge it has proved possible to produce striking results on even the most serious cases of disease due to staphylococci and other organisms.

This early work in Britain has now been fully confirmed in the United States, and there seems little reason to doubt that penicillin, with the further developmental work which is being undertaken everywhere, will fill an important place in medicine for the treatment of many infections. We are only at the beginning of its exploitation; further progress demands greatly increased supplies. Though no doubt a great deal will be produced from the mold, it is to be hoped that chemical progress will be such that penicillin, and even better substances than penicillin, may be produced in real abundance by synthetic processes.¹

When plentiful supplies are available it should be possible to treat those diseases which can be controlled by penicillin at the earliest possible moment instead, as is so often the case now, of using the drug as a last resort. When this may be done, an enormous amount of temporary and permanent disability, and even death, may be avoided.

¹ Note added by author June 1945: This position has now been reached.

RECENT ADVANCES IN ANESTHESIA¹

By JOHN C. KRANTZ, JR.

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INTRODUCTION

"Nothing in the whole realm of human effort has ever contributed so much to human comfort as the discovery of modern anesthesia."

Pain and discomfort are the arch enemies of man. To escape them and effectually combat them, he has ransacked the entire earth to find drugs to bring him a surcease of pain. During the middle of the sixteenth century Ambroise Paré operated without anesthesia, except for the administration of French wines, which would produce an alcoholic stupor. Only 120 years have passed since Ephraim McDowell removed an ovarian cyst from Mrs. Jane Crawford in Danville, Ky., without any anesthetic agent. She was then 47 years old and lived to see her seventy-eighth birthday. It is difficult for man today to appreciate the excruciating pain suffered by surgical patients in the preanesthetic days and, further, no one can with certainty estimate the impediment to surgical progress that the absence of anesthesia produced.

NITROUS OXIDE

Joseph Priestley, the discoverer of oxygen, prepared the first generally accepted anesthetic. Priestley was a Unitarian minister in Birmingham, England. In the congregation of this brilliant scientist-clergyman were three illustrious men: James Watt, who discovered the power of steam and holds the admiration of men in all walks of life; Erasmus Darwin, brilliant scientist and skilled clinician whose grandson, Charles, established a new order in biology; and William Withering, "Flower of English Physicians," discoverer of the use of the purple foxglove in edema of cardiac origin. In the year 1773, Joseph Priestley made nitrous oxide. To him it was a new chemical compound, a gas whose physical properties should be investigated. Priestley was unconcerned with its biological effects and died in Northumberland County, Pennsylvania, not knowing that nitrous oxide would confer a blessing of inestimable magnitude upon man.

A quarter of a century passed. Sir Humphry Davy, brilliant English chemist and physicist, made "Priestley's gas." It was then designated in chemical reports as "dephlogisticated nitrous gas." Davy

¹ Reprinted by permission from the Journal of the American Pharmaceutical Association, Scientific Edition, vol. 32, No. 11, November 1943.

inhaled nitrous oxide and observed a period of great exhilaration with an increase in pulse rate. In a letter to one of his friends he wrote: "I danced around my laboratory like a madman." But further than this Davy observed that continued inhalation of the gas would produce insensibility to pain. In fact, Davy anesthetized certain of his friends to unconsciousness with nitrous oxide. On July 3, 1798, Mr. Wedgewood called on Davy and he used nitrous oxide on him. He recorded in great detail his experiences, which read, in most respects, like a patient's account of losing consciousness under nitrous oxide. Davy suggested the use of nitrous oxide in medicine, but nothing was done about it.

The scene shifted to America. In Hartford, Conn., on December 10, 1844, G. Q. Colton was delivering a lecture on popular science. Among the experiments performed by Colton was the apparent hypnotism of certain members of the audience, presumably by means of his gesticulations. Meanwhile one of Colton's associates engulfed the individual in nitrous oxide. This made effective the hypnotic art of Colton. That same afternoon, a dentist whose name was Horace Wells was in the audience. He saw one of the people swoon, fall and hit his leg violently against a chair, without apparent sensation of pain. Through his scintillating intellect flashed the era of painless dentistry. The next day Wells persuaded one of his dental colleagues, Dr. Riggs, to extract one of his teeth, while under the influence of "laughing gas." Wells did not whimper. The first step in man's redemption from pain had been taken. Wells did not succeed in establishing the widespread use of his new anesthetic agent. In Boston, where he endeavored to employ it, the gas bag failed most inopportunistly, and Wells was hissed out of the room as a mountebank and charlatan. When death came prematurely to Wells, he did not realize what a tremendous and far-reaching influence his observations would have upon the comfort and even the destiny of the race.

This present decade, therefore, marks 100 years of use of nitrous oxide as a general anesthetic. During this period its popularity has waxed and waned, and during the last two decades the gas has definitely established itself for the smooth induction of ether-oxygen anesthesia.

Nitrous oxide is a colorless, odorless gas which is alleged to possess a sweet taste. The gas supports combustion only after the disintegration of the molecule into oxygen and nitrogen. Seeds cannot germinate or plants grow in an atmosphere of nitrous oxide. Nitrous oxide is very soluble in water, from two to three volumes of nitrous oxide dissolve in one volume of water. It is, however, like other general anesthetics, more soluble in oil than it is in water. Blood will dissolve a large volume of the gas. The gas does not combine with the hemoglobin. Owing to its greater solubility in oil than in water,

the gas as it is carried by the blood to the central nervous system partitions itself out of the blood into the lipids of the central nervous system producing narcosis. Induction is prompt, narcosis occurring within 1 to 2 minutes. Anesthetists have set forth the following effects from the inhalation of various concentrations of nitrous oxide:

<i>Effect</i>	<i>N₂O, Percent</i>	<i>O₂, Percent</i>
Subconscious analgesia-----	80	20
Complete analgesia-----	84	16
Light anesthesia-----	89	11
Complete anesthesia, dangerous hypoxia with incomplete relaxation-----	94	6

Like many other volatile anesthetics, nitrous oxide enters the body and leaves it unchanged. In other words, it is refractory to catabolism by biological processes. Its anesthetic action according to modern concepts is apparently due to the production of a reversible oxygen-want in the central nervous system. By means of drugs, hypoxia of the central nervous system can be produced by at least three mechanisms.

1. Formation of carbonyl hemoglobin (carbon monoxide poisoning).
2. Inactivation of the cytochrome oxidase in the cells (cyanide poisoning).
3. Inactivation of the cytochrome reductase in the cells (narcosis-nitrous oxide, ether, chloroform, etc.)

Substances used clinically as anesthetics affect the cells of the central nervous system according to the third concept but, in addition, they exhibit the property of affecting, first, the cells of the cerebral cortex; second, those of the spinal centers; and, last, the cells of the vital medullary centers.

Inexplosibility, safety, and availability are factors which give nitrous oxide a place of pre-eminence among the volatile general anesthetics.

ETHYL ETHER

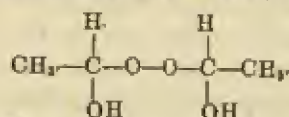
Crawford W. Long of Georgia used ether as a general anesthetic in 1842. He was familiar with some of the pharmacologic effects of ether and in Jefferson County there were many "ether frolics" which resembled modern parties of inebriates. He used ether also to deaden pain in the reduction of fractures and on James W. Venable to permit the surgical removal of a growth on the back of his neck. Unfortunate it is indeed that Long did not publicize his observations for apparently the first paper published by Long on ether appeared in 1849, 5 years after Wells' work with nitrous oxide, and 3 years after Morton's demonstration of the use of ether in Boston.

In Boston, a chemist named Jackson suggested the use of ether to a dentist named W. T. G. Morton, who was a pupil of Horace

Wells. Morton persuaded Dr. J. C. Warren, son of Dr. J. M. Warren, associated with General Putnam at the Battle of Bunker Hill, to permit him to use ether on one of his patients. On October 16, 1846, in Massachusetts General Hospital, Morton began the administering of ether to Dr. Warren's patient. From that operating room reverberated that memorable statement which has echoed down through the decades, "Dr. Warren, your patient is now ready." Dr. Warren commented that this was no humbug. Mr. Abbott, the patient, was fast asleep. Ether had found its place.

Shortly after this, Oliver Wendell Holmes, in a letter to Morton, conveyed the fact that he had assigned a generic name to ether and all such agents. He commented on the importance of a proper selection of a name, for Holmes held that it would be on the lips of every person of all races who in time to come would dwell on this planet. He coined the word "anesthesia" from the Greek *ἄσθησις*, perception, and the *ἀν* negative, namely, without perception. Ethyl ether is the most generally used of all volatile anesthetics. Its mode of action is like that of nitrous oxide. It is not decomposed in the body, but its presence in the cells of the central nervous system produces insensibility to pain and a hiatus in consciousness. Ether requires 6 to 8 percent concentration in the inspired air to produce anesthesia. During surgical anesthesia the concentration in the blood is approximately 150 mg. percent. The blood pressure remains essentially normal, respiration full and regular during ether anesthesia. The relaxation of abdominal musculature is complete with ether. The administration of the anesthetic agent in the circuit with oxygen instead of air seems to reduce the incidence of postanesthetic nausea and vomiting with ether. Postoperative abdominal distress and too great a degree of volatility appear to be the principal drawbacks to ethyl ether as an anesthetic.

Ether, when exposed to light and air, has a tendency to develop peroxides. These are explosive and also serve as pulmonary irritants, when ether containing them is employed as an anesthetic. The structure of ether peroxide, according to Wieland, is:



Dihydroxydiethyl peroxide

The Pharmacopœia requires that ether used for anesthetic purposes must be peroxide-free. The test is carried out as follows: "Shake 10 cc. of ether occasionally during 1 hr. with 1 cc. of a freshly prepared aqueous solution of potassium iodide (1 in 10) in a 25-cc. glass-stoppered cylinder of colorless glass, protected from light: when viewed

transversely against a white background, no color is seen in either liquid."

CHLOROFORM

When the news of this important discovery of ether bridged the Atlantic, James Simpson of Edinburgh, began an assiduous search for substances as good as, or perhaps better than, the American ethyl ether. It seems strange indeed that scientists in England did not precede those in America in the use of ether because Michael Faraday, distinguished pupil of Sir Humphry Davy, was one of the first chemists to produce ether. Simpson's experiments were fraught with many failures. Ether was better as a general anesthetic than most every substance that he and his associates tried. One day, as he was fumbling through the papers on his desk, he found a vial of a colorless liquid which had been sent to him by the German apothecary, Justus von Liebig. And Simpson tried it—the liquid was chloroform. Several times did he anesthetize himself and his associates, Keith and Duncan, to unconsciousness with at least apparent impunity. It is recorded that immediately Simpson recommended the use of chloroform to alleviate the pain of childbirth. To this the clergy of England objected. They contended that this pain was a penalty pronounced upon Eve for her transgression in the garden of Eden and in consequence all subsequent generations of women should endure it with patience and complacency. Simpson was a careful investigator, but also was astute at repartee. To this criticism he very aptly replied, "The Lord caused Adam to fall into a deep sleep before appropriating his rib; out of which he created Eve." God administered the first anesthetic. Queen Victoria, that pioneer of English customs, broke the spell of superstition by permitting Simpson's chloroform to be used in her seventh confinement.

Chloroform is about five times more potent than ether as an anesthetic. It is also much more toxic. The decline in the use of chloroform in general anesthesia is due to its striking toxic action upon the heart and liver. Ether does not exhibit this. Most deaths under chloroform anesthesia occur in the induction stages. The mechanism of the acute intoxication probably takes place in the following manner. Chloroform stimulates the vagus centrally and slows the heart. Through the excitation of induction endogenous epinephrine stimulates the cardiac accelerator, thus the simultaneous effect of stimulation and depression of the heart rate produces fibrillation of the auricles and ventricles. In addition, chloroform is carried from the alveolar air to the left chambers of the heart in concentrations which are cardiotoxic. Before this has been diluted by the general circulation, cardiac stoppage is produced. The approximate mortality under chloroform anesthesia is of the order of magnitude in 1 in 2,500; with ether, 1 in 10,000. It

is of interest to note that the fluorine analogue of chloroform, namely fluoroform, is neither anesthetic nor toxic.

ETHYLENE

After the discovery of chloroform there followed several barren decades in the field of general anesthesia and at the turn of the century the armamentarium of the anesthetist contained only nitrous oxide, ether, and chloroform augmented in a small measure by ethyl chloride. Through the first two decades of the present century no substantial gains were made. However, in 1922, ethylene was introduced by Luckhardt of the University of Chicago. It had been observed that traces of ethylene caused the fading of flowers and this observation had come to Luckhardt's attention. He was curious about it. He wondered what effect ethylene would have upon animal protoplasm. Systematically he tested the gas on lower animals and observed its anesthetic effects. Ascending in the scale of development, he observed that the anesthetic properties held for monkeys and finally he permitted himself to be anesthetized many times to unconsciousness and ethylene took its place among the general anesthetics. Perhaps this discovery illustrates the characteristics of a scientist, "one who has the simplicity to wonder, the ability to question, the power to generalize and the capacity to apply." High concentrations of ethylene are required to produce anesthesia (85 to 90 percent) and, to avoid hypoxia, the gas must be administered with oxygen. The gas mixture is extraordinarily explosive, and many tragic accidents have occurred owing to the explosion of the gas through ignition by static electric sparks. Undoubtedly this has militated against the widespread use of the gas in many places.

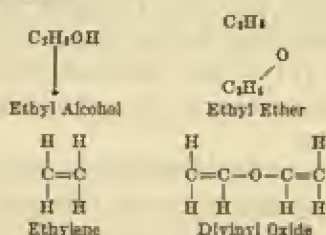
AVERTIN

In 1927, Willstätter prepared a general anesthetic, tribromethanol, marketed and employed as avertin, dissolved in amylene hydrate. The principle involved in this discovery is based upon the theory of narcosis announced by Meyer and Overton in 1900. Essentially this theory holds that the greater the oil/water solubility is, the more potent is its activity on the central nervous system. Alcohol has anesthetic properties. The alcohols of the aliphatic series of hydrocarbons of higher molecular weight such as amyl and octyl alcohols are less water soluble and more oil soluble, and their potencies as anesthetic agents are greater than that of ethyl alcohol. In avertin, three of the hydrogen atoms of the ethyl alcohol molecule having a combined atomic weight of 3 have been replaced by three bromine atoms, the sum of whose atomic weight is approximately 240. This increase in molecular weight increases the oil/water coefficient and simultaneously enhances the anesthetic potency of the compound. Avertin is administered rectally. Its anesthetic index or safety mar-

gin is narrow, i. e., the anesthetic and fatal doses do not vary by a great degree of magnitude. Therefore, most anesthetists prefer to use the drug in amounts equal to three-quarters of its anesthetic dose as a basal anesthetic and to complete the relaxation with nitrous oxide or ether. The drug is contraindicated in patients suffering with hepatic or kidney diseases. It is unfortunate that all of our data on the efficacy and safety of tribromethanol are befogged by the fact that it is employed dissolved in another anesthetic agent, namely, amylene hydrate. Furthermore, avertin is a fixed anesthetic, and threatened collapse under agents of this kind is much more difficult to combat than it is under volatile anesthetics. Under the latter, removal of the mask initiates the immediate course of removal of the agent from the circulating blood. Obviously, when a fixed anesthetic agent is used, this safety factor is unavailable.

DIVINYL OXIDE

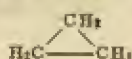
It occurred to Chauncey Leake (1) of the University of California in 1930 that it would be of great interest to prepare a hybrid molecule between ethyl ether and ethylene, i. e., a molecule which contained the essential features of the molecules of each of these anesthetics. Following this suggestion Major and Ruigh (2) prepared divinyl oxide, "Vinethene." The relation of these compounds to ethyl alcohol can be seen from the formulas.



Divinyl oxide is more powerful than ether. It is a liquid of very low boiling point. With it, anesthesia is rapidly induced, but owing to hepatic injury which may occur upon prolonged inhalation of this anesthetic agent, its use is confined to operations of short duration. One must not pass over the production of this new agent without paying due tribute to the fertility of the mind that conceived it. In its conception a molecule was designed, synthesized, and anticipated properties were later discovered to be inherent in it.

CYCLOPROPANE

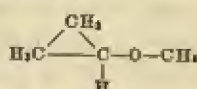
In 1930 Lucas and Henderson (3) of the University of Toronto announced the anesthetic properties of the hydrocarbon, cyclopropane. The structure of cyclopropane is seen in the following formula:



The gas is more potent than ethylene and hence permits the admixture during anesthesia of a larger percentage of oxygen. Relaxation of abdominal musculature is good during cyclopropane anesthesia. During the decade of its use the gas is now established as an important and dependable agent. Recognition of it in the United States Pharmacopœia XII bespeaks its growing field of usefulness. A brochure by Robbins (4) of Vanderbilt University on cyclopropane reviews the entire field.

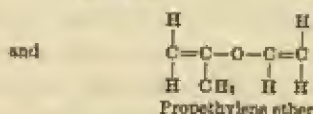
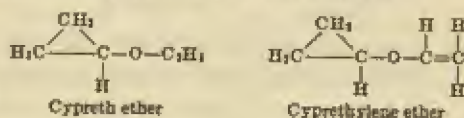
CYPROME ETHER

At the Medical School of the University of Maryland in 1939, Krantz, Evans, Carr, and Forman (5) succeeded in developing a chemical reaction for the convenient preparation of aliphatic cyclopropyl ethers. Four of these ethers have been prepared already, and three of them have had preliminary trial. One of these agents is cyclopropyl methyl ether known as cyprome ether; its structure can be seen by the following formula:



The pharmacologic studies conducted in the University of Maryland show cyprome ether to be more potent than ethyl ether and possibly safer. Its boiling point is 10° C. higher than ethyl ether which should be a distinct advantage for anesthesia in the Tropics. Black, Shannon, and Krantz (6) in 1940 reported the first 25 human cases of anesthesia with cyprome ether in "Anesthesiology." The compound appears to be promising.

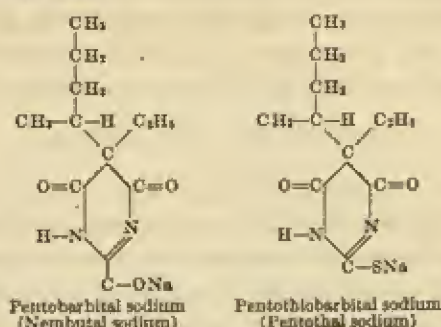
Other new anesthetics which have been produced by these investigators and are under study at the present time are:



PENTOTHAL SODIUM

Many years ago Fränkel prepared certain thiobarbituric acid compounds. Based upon insufficient evidence upon a very limited number of animals these compounds were discarded as not being worthy of therapeutic merit. Within the past 5 years these compounds have been reinvestigated and found to be very prompt-acting barbiturates, yet

the action is of very short duration. The one most extensively used in this country is pentothal sodium. Structurally this compound is pentobarbital in which the oxygen atom of the urea group has been replaced by a sulfur atom.



The widest use of this compound very recently has been in producing anesthetics by intravenous injection for surgical procedures of short duration. For this purpose 2 to 3 cc. of a 5-percent solution is injected in about 15 seconds. The injection is then discontinued to permit the complete effect to become manifest, which requires about 35 seconds. If relaxation has not occurred, an additional 2 to 3 cc. may be slowly injected.

The importance of pentothal sodium as a combat anesthetic cannot be overestimated. The mortality statistics with pentothal sodium are favorable and this agent appears to have warranted a permanent and enviable position among the anesthetic agents.

SPINAL ANESTHESIA

The use of local anesthetic agents in the spinal fluid to produce anesthesia dates back to the turn of the century. In the early days of this form of anesthesia, the deaths were so numerous that the popularity diminished. In more recent years, with more skillful technique and more numerous new synthetic local anesthetic agents to select from, this type of anesthesia has received a new impetus and is at present enjoying much popularity.

When a local anesthetic is injected into the spinal fluid impulses over all types of nerve fibers are blocked—sensory, motor, somatic, and autonomic. The sensory block occurs in 6 to 8 minutes which is followed by motor paralysis. The duration of the insensibility to pain and the motor paralysis is a function of the character and the concentration of the local anesthetic agent. Procaine hydrochloride in safe concentrations produces an anesthesia of 1-hour duration. Tetracaine hydrochloride (pontocaine) can be successfully used for a period of 3 hours.

There are many side reactions that may occur after the injection of an anesthetic agent intrathecally. There is a loss of motor tone which follows the paralysis of the vasoconstrictor fibers in the anterior nerve roots. The blood pressure consequently may fall to a very low level requiring the use of such drugs as ephedrine. Radiculitis, neuritis, meningitis, and palsies are some of the undesirable anesthetic sequelae that have occurred with the use of spinal anesthetics.

OUTLOOK FOR THE FUTURE

Perhaps there is no field in medicine where achievements have been as great and as far reaching as have been the advances in anesthesia. The scope of this review purposefully excluded advances in the techniques of anesthesia such as the invention of the anesthetic rebreathing machines, the endotracheal tube, the use of moist soda lime and conducting rubber devices for the grounding of static sparks. All of these have made definite contributions to anesthetic success and safety.

Future researches are certainly to be directed toward the end of developing a better volatile anesthetic agent than ether. It appears indeed to be possible. Intravenous anesthesia needs to be made safer. Other agents need to be investigated further and better antidotes than are now available must be found. The future must investigate further and understand more clearly, from the point of view of cellular physiology, what is meant by that profound hiatus in consciousness, so glibly referred to as surgical anesthesia.

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ASPECTS OF THE EPIDEMIOLOGY OF TUBERCULOSIS¹

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Despite the difficulty the American Public Health Association had a short time ago in settling upon a definition of an epidemiologist, I believe it is not impossible to say what epidemiology is. Epidemiology is the ecology of disease. It is the life history and environmental relationships of disease. It places less emphasis on how disease acts on the individual and more on its mass manifestations; little on symptoms, much on how it spreads and is influenced by all possible variant factors.

The study of tuberculosis is tremendously complex, and the results that have been obtained are confusing. This is not because the organism causing the disease is difficult to obtain and study. True, *Mycobacterium tuberculosis* grows slowly, but we have long had satisfactory culture mediums and suitable experimental animals are readily available. There is, however, no disease concerning which there are more disputed concepts and theories. Shortly after the tubercle bacillus invades the body successfully the tissues take on a new and specific capacity to react. If into the skin of such a person a tiny bit of the soluble protein of the tubercle bacillus is injected, there is a decisive response. The area becomes inflamed, slightly raised, unusually firm, and somewhat painful. It is, in fact, a typical area of response in inflammation. This reaction reaches its height on the second and third day and thereafter slowly fades away. This is a positive tuberculin test. By contrast, a person who has not been successfully invaded by the tubercle bacillus will give no reaction to a similar injection or indeed to one many times stronger in its tuberculin content.

The condition of the individual that causes him to react to the injection of tuberculin is the "tuberculin type of hypersensitivity." It would seem simple to determine whether it is better to be tuberculin positive or tuberculin negative, but it is not. Is this tuberculin type of hypersensitivity the same thing as immunity? It is not easy to decide, and any answer given will be disputed. Woodruff and Kelly (1942) observed: "Before tuberculosis can be controlled successfully

¹ Address of the retiring president of the Washington Academy of Sciences delivered at the 324th meeting of the Academy on February 17, 1944. Reprinted by permission from the Journal of the Washington Academy of Sciences, vol. 34, No. 6, June 15, 1944.

fundamental concepts concerning reactions of the host to the infectious agent must be clarified. Perhaps the most important of these concepts is the relation between the hypersensitive or allergic response and immunity." Shall we immunize our children against tuberculosis? We immunize them against diphtheria; why not against tuberculosis? In 1940, 60,428 persons died of tuberculosis in the United States and only 1,437 of diphtheria. It may be objected that tuberculosis is not a childhood disease. It is not, and it is much less so now than it was in 1900, but in 1940 a total of 2,787 children under 15 years of age died of tuberculosis, almost twice the total number dying of diphtheria.

When we have clinical tuberculosis where do we get it? Is it from within—the lighting up of an old arrested focus—or is it from without by contact, often repeated, with open cases of tuberculosis? We now favor the latter view, exogenous infection, but it has not been many years since the former view, endogenous infection, was our gospel. Years ago we used to speak of the childhood type of tuberculosis. Now we call it "first infection phase." In this form of infection the tubercle bacillus localizes in the outer parenchyma of the lower- or mid-lung field, and there is developed an area which, when it later becomes encapsulated, calcified, or perhaps even ossified, is known as a Ghon tubercle. Before this happens, however, the little colony of tubercle bacilli, often too small to be seen with the naked eye, establishes connection with functionally adjacent lymph nodes and there sets up a focus of tuberculous infection that in time usually becomes calcified and, if large enough, visible in X-ray plates. The tubercle and its involved lymph node form the Complex of Ranke. As a usual thing an individual harboring this pathology suffers, particularly if he is not a very young or a weakly person, few if any clinical symptoms. Some years ago it was believed that almost every child had such a "primary infection." Now it is known that most children escape any form of tuberculous infection and that "first infection phase" tuberculosis comes in both adults and children. Is it the same usually benign disease in adults that it used to be in children, or is it much more serious? We have a debatable proposition.

Years ago we used to speak also of the "adult" form of tuberculosis. Now we call it "reinfection phase" tuberculosis. This is tuberculosis developing in an individual who has had "first infection phase" tuberculosis and is thereby a different host from the individual never contacted successfully by the tubercle bacillus. In this form of disease the lesion usually appears in the upper third of the lung and does not involve the functionally connected lymph nodes. When such lesions heal they show less of calcification and more of resorption and fibrosis. Spread of this type of disease, which frequently occurs, is by caseation, liquefaction, and excavation. This "adult" type of disease can, of

course, occur in a child provided it is an individual who has had "first infection phase" tuberculosis. It was formerly thought that such disease arose chiefly from one's own reservoir of tubercle bacilli held over from an arrested "first infection phase" attack. The fact that overwork, worry, undernourishment, and other untoward socioeconomic factors predispose to tuberculosis fitted in very well with the idea that each man carried about his own potential tuberculosis and might light it up as an adult by lowering his personal resistance.

The following quotation from the American Review of Tuberculosis (Dobbie, 1920) is not the point of view held today:

In adults the problem of preventing infection requires very little attention. The great majority of adults have already been infected before reaching adult life. What adults have to fear most is not further infection from without, but an extension of the infection which they already have, leading to the development of a group of symptoms which we are pleased to call the disease tuberculosis. All adults should of course avoid prolonged and intimate contact with the grossly careless tuberculous person; but there is little to be feared through ordinary contact. It has been said that the careful consumptive is not a danger to anyone. This might be modified to read the consumptive is a grave menace to infants, less dangerous to children, and no danger at all to adults if reasonable care be exercised.

Let me emphasize again. We should not be afraid of the tubercle bacillus. For ourselves, as adults, as a rule we need fear no attack except from those that are now in our bodies. For the children, since we cannot permanently protect them from invasion, let us wisely choose the time when the bacilli are first to be met. If this be done, the tubercle bacilli may be transformed from a menacing enemy into a protecting friend. This is what should be taught to every adult, as comprising the knowledge in accordance with which he should live and act as an individual.

Today we favor the view that tuberculosis may be contracted from continued contact with open cases and that its incidence may be reduced by eliminating sources of infection from milk or meat; by minimizing contact with open cases through early and accurate diagnosis and isolation; and by proper care of those having tuberculosis including full attention to proper nutrition and conditions of living. What a change of point of view within a generation! Some areas are even working on the hypothesis that all tuberculosis can be prevented. Certainly one cannot develop tuberculosis without first becoming tuberculin positive. Hence, in certain parts of the country where conditions are favorable an effort is being made to place tuberculosis on the county accreditation basis. In 1940 the death rate for tuberculosis in the continental United States was 45.9 per 100,000, one of the finest rates anywhere in the world. It is a reasonable estimate that in that year about 50 percent of our total population were tuberculin positive. Minnesota has established county accreditation for tuberculosis. This "new idea in human tuberculosis control" provides that a

county shall be accredited in which there is an average annual death rate of 10 or less per 100,000 and a tuberculosis infection rate, as evidenced by a positive tuberculin test, of less than 15 percent among high-school seniors. At least 7 of Minnesota's 97 counties have already qualified for this honor.

Casual reference to tuberculous infection as something quite time extensive has probably been confusing to the reader. Reference to figure 1 should assist in the understanding of the early stages in the host-parasite relationship of the tubercle bacillus and man.

Some diseases are short-lived and decisive. The patient is sick 2 or 3 days and then is about his work. Such a disease is a mild attack of influenza. In typhoid fever, on the other hand, the patient may be ill 6 weeks or more, and there is a further period of convalescence to add

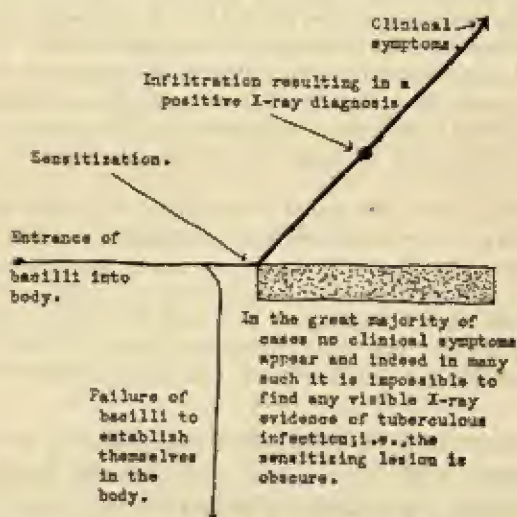


FIGURE 1.—The result of the invasion of the body by tubercle bacilli.

to the 6 weeks' loss of time from work. In tuberculosis there may be a very gradual onset involving 2 or 3 years before the patient has any symptoms at all. Probably every person in the United States has swallowed or inhaled at least one living tubercle bacillus even in this day of allegedly fine progress in the elimination of tuberculosis. In half, or more than half of us, the microbe did not successfully invade the body. (Some of the points involved in the host-parasite relationship bearing on this point are fascinating to contemplate but difficult to set in order, and they are graphically suggested in figure 2.)

Shortly (2 to 7 weeks) after the tubercle bacillus has invaded the body the tissues become sensitized and the host is altered profoundly, just how profoundly we do not yet know. The elicitation of a positive tuberculin test from such a person is only one aspect of the mat-

ter. The sensitized individual possesses a new reaction pattern, which he will keep as long as viable tubercle bacilli remain in his body.

Fortunately, the great majority of sensitized individuals do not progress farther toward clinical tuberculosis. Such individuals are harmless to others in their environment, for the tubercle bacilli causing the sensitization are locked within their bodies. Indeed, as Long has so well pointed out, the tuberculous individual does not enter into the epidemiological picture until his pathology is well advanced. Large lesions casate, liquefy, and erode into bronchi where bacilli are spread farther within the lung of the hapless patient or expectorated to the outside world. Interestingly enough, the number of tubercle bacilli becomes very great in an area of just this type, whereas they might have been rather few in the same area a month earlier.

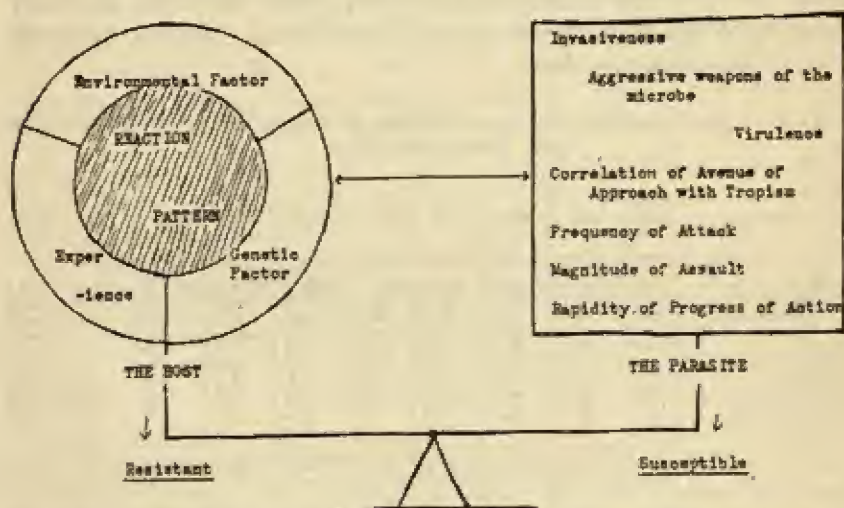


FIGURE 2.—Some of the factors entering into the host-parasite relationship, which have much to do in determining the outcome of an infection.

Only a few of those who become tuberculin positive for the first time will progress to the point where roentgenological evidence can be obtained that they are ill, and of these by no means all will advance farther to the point where clinical symptoms can be noted. Furthermore, if taken at the stage of minimal tuberculosis, the disease is easy to arrest. Even if arrested the individual will still, for a long time, likely for life, harbor some of the tubercle bacilli that multiplied within his body. It may seem odd that one can be in good health and play host to pathogenic organisms. Such a healthy arrested case should not be a source of danger to others, but it is important to point out that every extensive survey of adults reveals some of these individuals who are not satisfactorily arrested cases and who continue to work or even attempt to enlist in the Army or Navy while really suf-

fering from moderately advanced or even far advanced tuberculosis. Ironically, many of them are not even aware of the seriousness of their condition. The tubercle bacillus is not a vicious pathogen despite the fact that it causes the most important single disease from which man has ever suffered. It is therefore all the more important that the facts about tuberculosis be known, so that medical practice and science can continue adequately in the effort to solve the tuberculosis problem.

What is the present status of tuberculosis as a medical problem?

First of all, it is worthy of note that there has been a very marked decrease in this country in the number of deaths from tuberculosis. In 1900 the rate was 194.4 per 100,000; in 1940 it was 45.9; in 1942 it was 43.1. There was only 1 death in 1940 where there were 4.2 deaths in 1900. Not only has the number of deaths decreased but the distribution of those deaths has changed both within the total mortality picture and within the mosaic of tuberculosis itself. Table 1 will make some of these changes clear.

TABLE 1.—*Change in death rates (per 100,000) from 1900 to 1940 for tuberculosis and some other diseases*

Disease	Ratio 1900- 1940	1900	1905	1910	1915	1920	1925	1930	1935	1940
All deaths.....	1.59	1,719.1	1,588.9	1,468.0	1,317.0	1,208.0	1,169.1	1,132.1	1,094.5	1,076.4
Tuberculosis.....	4.2	194.4	179.9	153.8	140.1	113.1	84.8	71.1	55.1	43.9
Percent of all.....	2.6	11.3	11.3	10.4	10.6	8.7	7.2	6.2	5.0	4.2
Typhoid.....	31.3	31.3	22.4	22.5	11.8	7.6	7.8	4.7	2.7	1.9
Malaria.....	8.6	8.2	2.5	1.1	1.6	3.4	2.9	2.9	3.5	1.1
Measles.....	26.6	13.3	7.4	12.4	5.2	8.6	2.3	3.2	3.1	0.5
Scarlet fever.....	19.2	9.6	6.2	11.4	3.6	4.6	2.7	1.9	2.1	0.5
Whooping cough.....	8.5	12.2	8.9	11.6	8.2	12.5	6.7	4.8	3.7	2.7
Diphtheria.....	39.6	40.3	23.5	21.1	15.2	15.3	7.8	4.9	3.1	1.1
Total.....	17.6	112.9	71.5	59.1	45.6	52.2	29.3	22.4	18.2	6.4
Diarrhea in babies (-2).....	15.2	115.9	93.4	98.4	53.7	43.4	30.8	19.4	10.4	7.6

Data from the Bureau of the Census, based on the expanding Registration Area. Since 1933 this area includes all continental United States.

The rate for tuberculosis was 4.2 times as high in 1900 as it was in 1940. This is for all ages. The change has not been the same for all age groups:

Under 1 year.....	12.6	25-34 years.....	5.2	65-74 years.....	3.1
1-4 years.....	8.2	35-44 years.....	4.2	75-84 years.....	3.4
5-14 years.....	6.5	45-54 years.....	3.2	85 years and up.....	3.2
15-24 years.....	5.3	55-64 years.....	2.9		

It will be noted that in 1900 tuberculosis accounted for 11.3 percent of all deaths. By 1940 this figure had fallen 2.6 times, to 4.2 percent.

Another significant point not shown in the table is that the disease is becoming pulmonary in type. In 1940, of the 60,428 deaths from tuberculosis, 55,576 deaths were pulmonary tuberculosis. Just over 8 percent were tuberculosis of the central nervous system, gastrointestinal tract, the bony structures, the skin, the lymphatics, the genitourinary system, generalized tuberculosis, and infection of other organs. Forty years ago this figure would have been much higher. Other

changes we may note are a great decrease in the proportion of deaths from tuberculosis in infancy, childhood, and adolescence, and even in early married life. There has been a relative increase in tuberculosis deaths in the middle and later years of life, and there is no longer for Whites a peak in the curve representing deaths from tuberculosis. It is rather a plateau extending over three or four of the most important decades of life.

Tuberculosis mortality is much higher among males than among females. In the States Relations Division of the United States Public Health Service there is now a Tuberculosis Control Section headed by Dr. H. E. Hilleboe. Tuberculosis mortality in the United States, 1939-1941, was reviewed by three Public Health Service workers in Public Health Reports for October 1, 1943. They point out that for these 3 years, 1939-1941, the male death rate (53.6) was 41 percent higher than the female rate (38.1). This excess in mortality among males is higher for tuberculosis than that from deaths from all causes. For these 3 years tuberculosis was seventh in numerical importance among the leading causes of death. There are very large racial differences in tuberculosis mortality, the rate for Negroes in 1940 (123.5) was nearly three and one-half times that for Whites (36.6). The rate for Indians, Chinese, and other races was about double that for Negroes. Among non-Whites tuberculosis was third in numerical importance as a leading cause of death. Another point, hotly disputed in the epidemiology of tuberculosis, is whether the Negro tuberculosis experience is the result of the less favorable socioeconomic conditions under which they live or is due to inherent biological racial differences between Whites and Negroes.

Tuberculosis is still among the three leading causes of death for a relatively large portion of the life span (15 to 49 years of age). It holds first place at ages 15 to 34, second at 35 to 39, and third at 40 to 49. For males tuberculosis is among the first three leading causes of death at ages 15 to 54, and for females at ages 10 to 44. For Whites only, it is among the first three leading causes of deaths at ages 15 to 49 for both sexes, ages 20 to 54 for males, and 15 to 44 for females.

Table 1 reveals the fact that though we have made worth-while progress in the fight against tuberculosis this progress compares unfavorably with advances made in the control of such diseases as typhoid and diphtheria, and indeed for the whole group listed together in the table, viz, typhoid, malaria, measles, scarlet fever, whooping cough, and diphtheria. In 1900 tuberculosis caused only 1.7 times as many deaths as this arbitrarily selected group. In 1940 this figure became 7.1 by virtue of the more perfect control of the selected group of diseases. Significant, too, is the more marked diminution in the deaths that occur in children under 2 years of age from diarrhea and enteritis. That improve-

ment in the tuberculosis picture has occurred is, of course, true. Our chances of dying of tuberculosis are now computed at a much more favorable level. It is also of interest to note that the percentage of persons tuberculin positive has been falling. For instance, one of the earliest reports on the results of tuberculin testing of a student group was based on a study conducted at the University of Minnesota in 1928. Thirty-one percent of 2,000 students were found to be tuberculin positive. In 1941-1942 only 17 percent of 5,481 students were positive. Thus in 13 years there was a reduction of 45 percent in the number of tuberculin reactors. Similar information gathered from school surveys all over the country is much more significant than may on first thought occur to one. We are fast becoming a nation of unsensitized individuals with respect to tuberculosis. There has long been a considerable school that has maintained that sensitization in the sense of tubercularization without progression is protection. What, they ask, will be the outcome as more and more tuberculin-negative children become adults and first meet the tubercle bacillus under wartime and reconstruction conditions? It is possible that the medical-school tuberculosis problem may cast light upon this matter, but before that point can be presented it is logical to consider the effect of war on tuberculosis morbidity and mortality.

What was the effect on the tuberculosis rate of World War I? Dr. Long describes the situation in Europe by observing: "After years of continuous drop, the rate began rising in 1915 and by 1918 had reached a figure in all countries about 25 percent higher than at the beginning of the war." Wolff has described the privations of the period as "an involuntary mass experiment . . . of more epidemiological importance than endless theorizing on the pathology of tuberculosis." These statements may be amplified in the words of an August 1941 article in the *Statistical Bulletin of the Metropolitan Life Insurance Co.*, in part as follows:

The experience of the World War of 1914-18 affords an indication of what is likely to occur. None of the belligerent countries escaped an increase in tuberculosis then, and practically all of the neutral countries of Europe suffered either an increase in tuberculosis or a slowing up of the prewar rate of decline. The most reliable data for the period relate to the trends among women and children in England and Germany. Among English women the mortality from pulmonary tuberculosis rose steadily during the war to a peak in 1918, when it was over 25 percent higher than in 1913. Among German women the pulmonary tuberculosis death rate rose slowly at first, but after 1916 the increase was very rapid, so that by 1918 the rate was nearly 75 percent above that of 1913. Indeed, in Germany the death rate from tuberculosis among women did not return to the prewar level until 1921; and this improvement was not maintained for a few years following. The rate of increase among German females was greatest at ages under 20 years. Among children the rate in 1919 was even higher than during the war.

Far worse was the situation among the other belligerent countries of the Continent, but only fragmentary statistical data are available to show the frightful increases in some of these areas. The statistics of tuberculosis mortality in France during the war are defective because of the absence of facts for the invaded regions, where the situation was at its worst. The data for the uninvaded portion show a sharp increase, particularly in 1917 and 1918. In the latter year the recorded rate was about 20 percent higher than in 1914. The accuracy of these statistics is doubtful, and the actual increase was probably larger. To some extent the same observation probably holds for Italy, but in that country even the recorded deaths from tuberculosis in 1918 were over 40 percent in excess of the 1914 rate.

A few examples will show the extremely bad conditions in Belgium and in eastern and southeastern Europe. In Brussels the death rate from tuberculosis doubled during the war, from 177 per 100,000 in 1914 to 390 in 1918. In Vienna the rate in the period 1915-18 was 20 percent higher than in 1911-14, and in the early postwar years it increased to 50 percent above the prewar rate. In Budapest the number of deaths from the disease in 1917 was nearly double that of 1913, and it was but little less in 1918. In Warsaw the rate in 1917 was 840 per 100,000, as compared with 306 in 1913; in Cracow during the same period the rate increased from 487 to 908 per 100,000. In Belgrade the tuberculosis death rate in 1918 reached the almost incredible figure of 1,400 per 100,000.

Typical of the trend of tuberculosis in the neutral countries of Europe during the World War are the experiences of the Netherlands and Switzerland. In the former, the death rate from the disease rose steadily, until in 1918 it was nearly 50 percent above the 1914 figure. In Switzerland, where the trend was sharply downward before the war, the rate continued to fall at first, but rose in the latter part of the war to a peak of 207 per 100,000 in 1917, or 6 percent above the rate in 1914.

In our own country the mortality from tuberculosis showed little change during the World War period as a whole, but even here there was a slight increase in the death rate during the period of our active participation in the war. Thus the death rate in the original Registration States declined from 148.6 per 100,000 in 1914 to 143.8 in 1916, but then rose to 147.1 in 1917 and further to 151.0 in 1918.

These increases come about through break-down in resistance to disease on the part of the host, to increase in opportunities for infection, and to a decrease in or, indeed, collapse of facilities available for proper recognition, isolation, and treatment of disease. Specifically some of the factors for tuberculosis are:

1. The entrance of women into heavy and fatiguing industry.
2. The return of the older age groups to active employment.
3. The return to work of persons of either sex or any age physically unfit to work.
4. Long hours of work often emotionally compensated for by long hours of strenuous or injudicious relaxation—"burning the candle at both ends."
5. Relocation in areas of intense war-industry activity resulting in congested living conditions without adequate sanitary facilities.

6. Relocation in areas of intense war-industry activity where tuberculosis rates may be high by persons coming from areas where tuberculosis rates are low.

7. Congestion in concentration camps, war prisoners' camps, evacuation depots or camps, and air-raid shelters.

8. Use of hospital beds formerly allocated to the tuberculous for more urgent war needs or actual destruction of hospital facilities by the bombings or bombardments of "total" warfare.

9. Loss of trained personnel to the war need—physicians, nurses, attendants, laboratory workers, and social workers—all needed to care for an increasing load of tuberculosis patients.

10. Food shortages, both qualitative and quantitative.

11. Impossibility for perfect rest conditions so necessary for the tuberculous and the pretuberculous.

12. Worry and anxiety over the fate of one's relatives or even of one's country.

One of these points deserves particular emphasis as far as this country is concerned. As pointed out in an editorial in the *New England Journal of Medicine* for January 27, 1944, "it is estimated that 25,000 had been diagnosed (at induction) to have a disease that neither they nor their friends would have suspected under prewar conditions. And how are these patients, many of whom need sanatorium treatment, going to be accommodated by the currently restricted personnel of the sanatoriums?" Early in 1942 the number of beds for tuberculosis patients in this country totaled 97,726, or 1.62 per annual death, which is at best well below the minimum standard set at 2 beds per annual death and far below the more ideal standard of 3. In 1942 only seven States and the District of Columbia had met the minimum standard. It is quite possible that under present conditions of personnel shortage the paper figure of 97,726 beds available for tuberculosis patients must be considerably discounted. Where fighting is actually going on the condition is, of course, much worse.

Just what has happened thus far in the present war? Hilleboe states that by the last half of 1942 in the United States the Bureau of the Census, by a sampling process, had sensed an increase in tuberculosis in the "critical areas," although the total figure for 1942 represents an all-time low rate of 43.1 per 100,000. In England he notes a 13 percent increase in deaths from all forms of tuberculosis in 1941 as against 1938. This represents more than 3,000 additional deaths each year from a preventable disease. Recently in the *British Medical Journal* (January 8, 1944) it is stated that in Belgium the registered cases of tuberculosis increased from 69,079 in December 1941, to 109,511 in February 1943, an increase in rate from the high figure of 830 per 100,000 to the startling figure of 1,330 per 100,000. If there

are 10 clinical cases of tuberculosis for every annual death, we have in the United States less than 600,000 cases at the present time or only six times as many as now exist in little Belgium, which has perhaps only one-twentieth of our population. Many of our people are in, or shortly will be in, these unfortunate European countries. It would seem a safe prophecy to venture that the tuberculosis rate in this country may be slightly increased for a short period, but it should within a very few years again resume its downward trend.

In view of the very low rate now obtaining (43.1 in 1942) it would be reasonable to expect a greater set-back relatively than we experienced at the end of World War I. The magnitude of this set-back may not be so much one of significantly increased rate as of slowness to get under way again on the downward trend. For a disease as widely seeded in our population as tuberculosis and for a population more completely involved in abnormal war activity than was the case in World War I, it would not be surprising if this were to be so and the very favorable rates now attained would seem to be advanced posts we may have to abandon for some time. One factor in this slightly pessimistic prediction is our closeness to and commerce with the rest of the world in many parts of which tuberculosis is rampant.

At one time the hope was expressed that we might be able to eradicate tuberculosis by a given date—say 1960. It should be understood that any such statement was merely a slogan, a cry behind which to rally the forces fighting the great white plague. As Frost ably pointed out in one of his last papers, entitled "How Much Control of Tuberculosis?" it "is not necessary that transmission be immediately and completely prevented. It is necessary only that the rate of transmission be held permanently below the level at which a given number of infection-spreading (i. e., open) cases succeed in establishing an equivalent number to carry on the succession. If, in successive periods of time, the number of infectious hosts is continuously reduced, the end result of this diminishing ratio, if continued long enough, must be the extermination of the tubercle bacillus." I am not aware that Frost ever set any date for this millennium. As a very humble student of epidemiology I am sure I cannot. I doubt though if under present war conditions we have any reason to anticipate any lowering of the death rate for the entire country from 43.1 to even 10 per 100,000 for several decades. Many millions of Americans are already tuberculin positive; thousands of unrecognized advanced cases of tuberculosis exist today; Europe and indeed most of the rest of the world is heavily tubercularized. It is too much to expect tuberculosis death rates to continue to drop as rapidly as they have in the past. To reduce 194.4 by 10 percent is not so difficult as to reduce 43.1 by 10 percent.

One other point that Frost makes deserves our attention. He states: "It is highly probable that the cyclic changes in prevalence which are observed in some diseases are brought about chiefly by evolutionary changes in the characteristics of the specific microorganisms, the causes of which are to be found in uncontrolled natural forces." Frost mentions scarlet fever and diphtheria as two of the diseases that within the past 100 years have greatly changed, although in the case of diphtheria the change reversed itself and diphtheria is again a problem of some significance in parts of the world. Smallpox, since the Spanish American War, has been relatively mild when it has occurred in this country, and in 1942 caused but two deaths. It could be possible that cyclic changes may be taking place in the nature of the tubercle bacillus making it less invasive, but whether this is so, how long it will continue, or whether it will reverse are propositions very difficult of proof. Again, case finding among medical students and physicians yields results with suggestive implications for this point.

Case finding means looking for cases of a given disease. It is done to discover unrecognized cases that should be brought under treatment for their own good and isolated or educated so that the public health may be protected by removing active sources of infection. Although useful for several diseases such as malaria and hookworm, even syphilis, case finding is particularly adapted to tuberculosis. It is possible through tuberculin testing to discover those belonging to the tuberculin-positive group of persons who can have tuberculosis and, by X-ray examination, to detect which of these have physical signs almost certain before long to produce clinical symptoms. Such individuals may be satisfactorily arrested with a minimum of treatment and loss of time whereas if the minimal case is not discovered in its incipiency a moderately advanced or even a far advanced case may result which is difficult or impossible to arrest. The great advantage to the careful examination of the would-be soldier or sailor is that tuberculosis is discovered, as never before, in the stage in which it is possible to do something about the matter. From the first approximately 400,000 men appearing for the Canadian Army, 1 percent were rejected for tuberculosis. Of 3,530 of these rejectees, there were 1,970 with minimal tuberculosis, 1,298 moderately advanced cases, and 262 far advanced cases. This ratio of the different clinical types (and the same is true for all other large-scale screenings) is the exact reverse of what occurs when we let nature take its course. In the past, minimal cases have been a minority in the treatment program with moderately advanced and far advanced cases constituting the great majority of cases coming to the attention of the physician and the care of his sanatorium. It is to be hoped that although we are at war care will be taken that the

young men and women found to have tuberculosis will be adequately cared for.

Tuberculin testing is time consuming and costly and, I regret to say, is sometimes omitted from the case-finding set-up. Celluloid films, 14 by 17 inches are also very expensive, and several substitutes have been worked out making it possible to examine the lungs of all members of a group (a good case-finding team can do 500 persons a

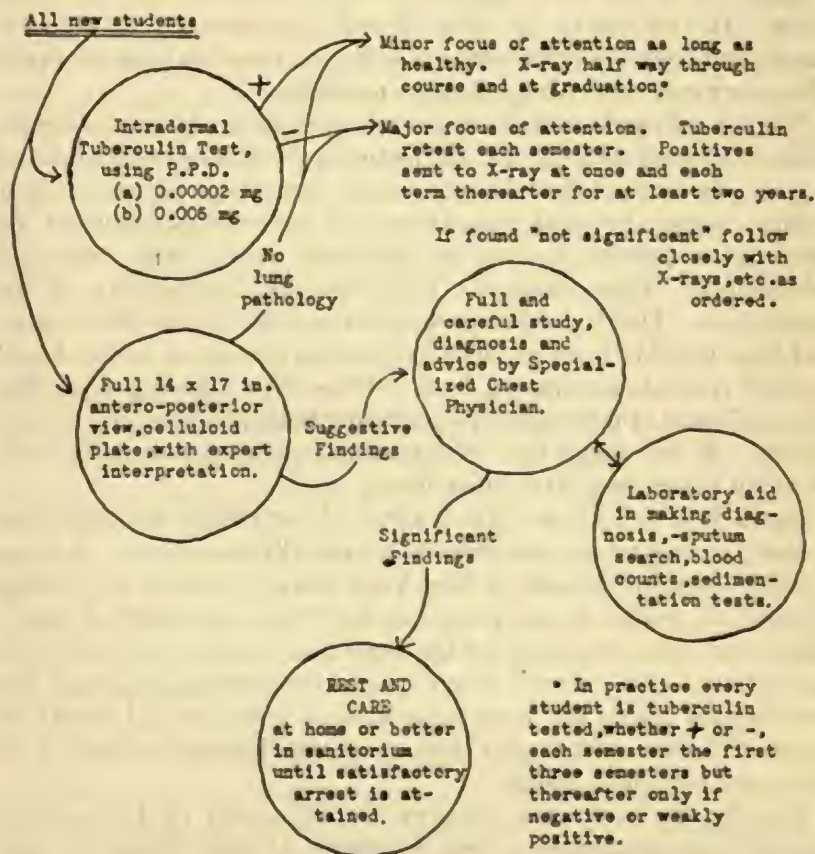


FIGURE 3.—Tuberculosis case-finding program at the School of Medicine, The George Washington University.

day) at a reasonable cost. While this expedient works and is therefore justified, from the epidemiological point of view it is distinctly faulty because the tuberculin test gives information we must have for the proper understanding of the disease, and the large plate provides a permanent record unequalled by most of the less costly substitutes. At George Washington University Medical School, through the interest and cooperation of the dean, a proper and complete case-finding program has been in progress almost 5 years. The organization and operation of this program are graphically indicated in figure 3.

It will be seen from figure 3 that five different agencies must be integrated in the program. These are the tuberculin-testing group, the X-ray group, the chest-physician group, the laboratory group, and the sanatorium group. Coordination is best effected by that agency having most student contact, which in our institution is the tuberculin-testing agency represented by the writer. When there is sufficient interest in the program on the part of the coordinator the cooperation of the other agencies is easily obtained and cheerfully given. In addition to the value of such a program to the health of the student body the tuberculosis case-finding program is an admirable laboratory experiment in preventive medicine.

When it was realized that exposure to open cases of tuberculosis had to be considered as an important factor in the etiology of the disease it was only natural that thought turned to medical personnel—physicians, nurses, hospital attendants, and students of medicine and nursing—as persons having an industrial hazard with respect to tuberculosis. Three examples will illustrate the validity of this assumption. Diehl and Myers reported in 1940 that at Minnesota it had been possible to check effectively on the careers of 1,673 of 1,894 medical students graduating from 1919 to 1936. Among these there were 107 cases of tuberculosis, 5 occurring before college, and 47 after college. It was found that 46 deaths had occurred among the 1,673, of which 11 had been from tuberculosis.

Again it is well known that inmates of our mental hospitals form a group among whom tuberculosis is especially important. A recent study of such individuals in New York revealed that on the average tuberculosis deaths in such groups in this State were relatively twelve times more numerous than for the State as a whole. In certain such institutions in this country where careful case-finding programs have been carried out on the attendants, rates of infection and actual evidence of disease much higher than occurs for other individuals in the same area have been found.

Thirdly, the early experience at the University of Pennsylvania revealed the significance in that institution of tuberculosis for medical students. Less than 10 years ago among 514 Pennsylvania students 5.8 percent of significant tuberculosis was found. Happily, results in most other schools are much better, and in fairness to Pennsylvania it should be pointed out that subsequent studies there have revealed a very much lower rate. Nevertheless, there seemed to be much logic to the statement made in 1930 by Stiedl of Trudeau when he said: "Tuberculosis might be called an industrial hazard for the medical profession. It is the most important chronic disabling disease for the medical student, the young physician and the nurse."

In 1939, a case-finding program at George Washington University School of Medicine was instituted. For many years prior to this, as I shall show presently, we had been making tuberculin surveys of all students, but a complete case-finding program had not, prior to 1939, been in existence in our institution. It is greatly to the credit of my former colleague, Dr. John H. Hanks, now in the Philippines, and Dr. David James, then president of the junior class, that they furnished much of the initial enthusiasm needed to get the program under way. The interest from the first of Dean Walter A. Bloedorn and the whole-hearted cooperation of the roentgenological and chest-physician group insured the success of the project. We have already indicated in a diagram how tuberculosis case finding works. It remains merely to give some of the results and to make a few observations.

The percentage of tuberculin-positive reactors among 14 consecutive classes totaling 1,007 students at George Washington University School of Medicine is shown in table 2. With so many tuberculin-negative students in school, a situation true in most other schools also, it was only natural to expect that many of them would become tuberculin positive. A good many of these tuberculin-negative students did become tuberculin positive but not nearly so many of them as one might expect. Washington is in an area of high tuberculosis mortality (1940 figures, entire U. S. A., 45.9 per 100,000 population; District of Columbia, 64.4; Maryland, 79.1; Virginia, 58.1), and our students certainly come into contact with tubercle bacilli. We were particularly impressed by the large number of those who were originally tuberculin negative and who remained negative through a complete medical education in Washington, D. C. Data on this point are presented in table 3.

TABLE 2.—Tuberculin tests on 14 consecutive medical classes at the George Washington University

Class	Status	Number	Percent positive
1936	Sophomore	62	82.2
1936	Freshman	71	98.5
1937	do.	69	78.2
1938	do.	74	84.0
1939	do.	65	55.3
1940	do.	64	60.9
1941	do.	69	69.5
1942*	do.	71	42.2
1943	do.	74	44.6
1944	do.	65	46.1
1945	do.	78	34.6
1946	do.	77	40.2
1947	do.	83	53.0
1948	do.	85	43.5

*This school has been on the accelerated plan since before Pearl Harbor; the entering classes no longer require 4 years for graduation.

TABLE 3.—*Tracing medical students, originally tuberculin negative*

Class	Total number of students tuberculin negative as freshmen	Number of these who left school	Number who completed all 4 years	Of these, number graduating tuberculin negative	Percent
Graduating November 1943.....	35	5	30	22	73
Graduating February 1943.....	42	6	36	21	58
Graduating 1942.....	40	3	37	23	62
Graduating 1941.....	21	5	16	7	44
Graduating 1940.....	24	6	18	13	72
Graduating 1939.....	30	6	24	11	46
Total.....	192	31	161	97	60

Of the 64 students, originally tuberculin negative, who became tuberculin positive, 4 developed clinical tuberculosis—1 man losing 2 years, 1 losing 1 year, and 2 no time loss. All 4 at present are in fine physical condition.

We were further impressed by the fact that a considerable number of medical students who gave weakly positive tuberculin tests later became negative. Students were not followed prior to 1939 through all semesters; hence the figures on this point do not include all our approximately 1,000 students. Of those followed (666), however, 134 have reacted only to the strong dose of purified protein derivative. This represents a low grade of sensitivity due perhaps to an almost negligible original sensitizing lesion or to a lesion almost completely sterilized or possibly, in an occasional case, to a nonspecific reaction. Nine classes are included in this aspect of the study, four of which are still in school, on whom obviously the data are not yet complete. In the five classes concerned that have graduated 56 showed weakly positive reactions as freshmen. Of these, 18 showed stronger reactions as they progressed through school, indicating some sort of sensitizing or immunizing process at work. Six became entirely negative and one became weaker in tuberculin reactivity, 22 remained the same, and a few of the original freshmen did not graduate. Among the 666 students of these nine classes 319 were positive to some strength of tuberculin as freshmen (47.9 percent). Of these, 134 (42.0 percent) were weak reactors. Among the 323 students of the last four classes there were 139 reacting to tuberculin (43.0 percent), of whom 78 were only weakly positive (56.1 percent). Among the 343 students in this series who have graduated there were 180 tuberculin reactors (52.4 percent), but of these only 56 were weak reactors (31.1 percent).

Several points may be made regarding these data. An environment containing tubercle bacilli does not prevent a certain number of weakly positive tuberculin reactors from becoming negative. These individuals may be thought of as resistant strains of the human race. Our newer students are showing not only a lower total tubercularization rate but also a tubercularization of less intensity. Tubercle bacilli in the environment are doing less to medical students than

formerly. This is susceptible to three interpretations. The tubercle bacilli in the environment are becoming fewer; they are losing invasiveness and virulence; or, thirdly, the resistance of the young white American to tuberculosis is increasing. The first point is obvious but can hardly be the whole explanation. I believe we miss the full significance of the data if we do not also allocate some importance to each of the other two explanations.

Weight is added to this suggestion when we consider that the total number of tuberculin-negative students in the school, all presumably susceptible to successful invasion by the tubercle bacillus, is increasing. This number is the census made up each semester after the tests are done. In November 1941 there were 147 tuberculin-negative students in the school. In June 1942 this number was 157. In November 1943 it was 166 among 313 students, or a student body only 46.9 percent tuberculin positive. There has been a slight increase in the total number of students in the school, but this has been balanced off by the fact that our last two classes, though the initial tuberculin-positive rate was low, had higher percentages than the average of the preceding four classes (48.3 as against 41.3 percent). Furthermore, since this program was started in 1939, only nine students have been found with minimal tuberculosis, although three others were detected shortly following graduation. At the present time, with 313 students in attendance, not one has minimal tuberculosis. This fine record surpasses that revealed in almost any mass survey of adults. Among 28,098 United States Government employees recently surveyed, 1.1 percent had recognizable tuberculosis (60.7 percent minimal; 35.3 percent moderately advanced; 4.0 percent far advanced).

It has been our purpose in presenting these observations to emphasize that, although remarkable progress has been made in combating tuberculosis, that progress has not equaled advance achieved in controlling other well-known diseases. We must believe that tuberculosis is still a major problem. Its eradication may be set back by the war but not irrevocably. Tuberculosis morbidity and mortality can be reduced to a satisfactorily low level, but I do not expect to see in my lifetime, the absolute elimination of the disease. Our evidence suggests that the tuberculosis problem is not at present unduly significant for medical students and that there is some ground for considering either that the young white adult has more resistance to the tubercle bacillus than his father possessed or that the *Mycobacterium tuberculosis* is losing some of its virulence. Possibly a little of both is true.

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